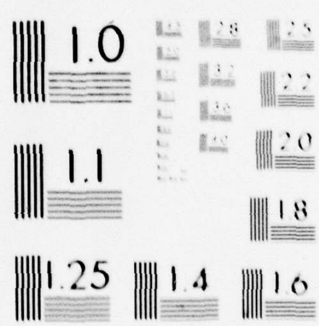
AD-A075 949 LOCKHEED-CALIFORNIA CO BURBANK F/G 1/3
GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS USER'S MAN--ETC(U)
SEP 79 M A GAMON, G WITTLIN, W L LABARGE DOT-FA75WA-3707
UNCLASSIFIED LR-28307-VOL-2 FAA/RD-77/189-V2-REV NL

1 OF 3
AD
A075949



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Report No: FAA-RD-77-189, II (Revised)

GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS USER'S MANUAL

VOLUME II

INPUT-OUTPUT, TECHNIQUES AND APPLICATIONS

Max A. Gamon

Gil Wittlin

William L. LaBarge

September 1979
(Revision)

Final Report

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Systems Research & Development Service

Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States government assumes no liability for its contents or use thereof.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-RD-77-189 II (Revised)		(11)

4. Title and Subtitle
(6) General Aviation Airplane Structural Crashworthiness User's Manual. Volume II - Input-Output Techniques and Applications. Revision.

5. Report Date
Sep[redacted]79 (Revision)

6. Performing Organization Code

7. Author(s)
M. A. Gamon, G. Wittlin, W. L. LaBarge

8. Performing Organization Report No.
(14) LR-28307-VOL-2

9. Performing Organization Name and Address
Lockheed-California Company
Burbank, California

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
(15) DOT-FA75WA-3707

12. Sponsoring Agency Name and Address
U. S. Department of Transportation
Federal Aviation Administration
Systems Research and Development Service
Washington, D. C. 20590

13. Type of Report and Period Covered
(9) Final rept.
Jun[redacted]76 [redacted]Feb [redacted]78,

14. Sponsoring Agency Code
Federal Aviation Administration
ARD-520

15. Supplementary Notes
The Cessna Aircraft Company participated as a subcontractor. (12) 253

16. Abstract This document provides a comprehensive description of program KRASH, as modified under Contract DOT-FA75-WA-3707. Included in this Volume of the User's Manual are the following sections:

(18) FAA/RD

- Section 2 - User's Guide
- Section 3 - Math Model Development
- Section 4 - KRASH Data Requirements
- Section 5 - Typical Model Arrangements

(19) 77/189-V2-REV

The Volume II has been established in such a manner that it can readily be updated as more data becomes available. The subject matter contained within each section can be expanded or revised, as necessary, without affecting the other sections. Each section contains its own numbering system which facilitates the task of updating the document.

This revision supersedes initial report with identical title and number.

(10) **Max A. /Gamon, Gil /Wittlin**
William L. /LaBarge

17. Key Words	18. Distribution Statement
User's Guide, Math Model Development, Program KRASH, General Aviation Airplane, Crashworthiness, Structural Arrangements	Document is available to the public through the National Technical Information Service, Springfield, VA 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	252	- -

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

209 970

METRIC CONVERSION FACTORS

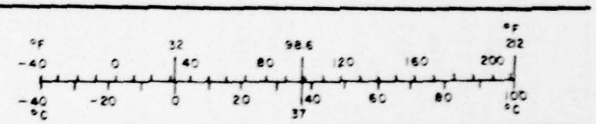
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



FOREWORD

This report was prepared by the Lockheed-California Company under Contract DOT-FA75-WA-3707. The report contains a partial description of the effort performed as part of Task II and covers the period from July 1976 to December 1977. The work was administered under the direction of the Federal Aviation Administration with H. Spicer acting as Technical monitor.

The program leader was Gil Wittlin of the Lockheed-California Company. Important contributions were made to the program by the Cessna Aircraft Company, which participated as a subcontractor. Under the direction of D.J. Ahrens and W.B. Bloedel, the Cessna Aircraft Company provided valuable data with regard to general aviation structure and designs. M.A. Gamon of the Lockheed-California Company, supported by W.L. LaBarge, refined program KRASH. H. Weinberger of the Lockheed-California Company provided valuable computer programming support. P.C. Durup of the Lockheed-California Company assisted in the preparation of reports. The Lockheed effort was performed under the supervision of J.E. Wignot.

SUMMARY

This document provides a comprehensive description of program KRASH, as modified under Contract DOT-FA75-WA-3707. Included in this Volume of the User's Manual are the following sections:

- Section 2 - User's Guide
- Section 3 - Math Model Development
- Section 4 - KRASH Data Requirements
- Section 5 - Typical Model Arrangements

The Volume II has been established in such a manner that it can readily be updated as more data becomes available. The subject matter contained within each section can be expanded or revised, as necessary, without affecting the other sections. Each section contains its own numbering system which facilitates the task of updating the document.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

SECTION 1

INTRODUCTION

Program KRASH has several features which can be used effectively to evaluate crashworthiness capability of vehicles during the initial stages of a design. Conceptually the program is designed to define the general behavior of structure and to provide data which can be utilized to assess chances of occupant survivability during a severe crash environment. While KRASH currently contains one measure of injury potential (Dynamic Response Index, DRI), the data obtained from KRASH are more useful as input to more complex seat-occupant-restraint system models. Since the program utilizes simplified and approximate representations of structure, it best can be described as a preliminary design tool. Although the program provides for as many as 80 masses and 100 members, modeling to the maximum capacity of KRASH should be exercised with care. For light fixed-wing airplanes, the use of a large number of node points can be expected to result in representing elements which may have relatively high natural frequencies. Since KRASH utilizes a numerical integration technique, the proper interval of integration is very sensitive to the system frequencies, and unless some simple preliminary checks are made for the math model that is developed, instability problems can develop. These instabilities can be avoided or eliminated by following simple guidelines. From an economic standpoint, it is desireable to develop the simplest math model representation of the actual structure feasible while obtaining an acceptable level of accuracy. The smaller the model the less input data are required, the computer cost is reduced proportionally, and review of the output data can be expedited. The question then is how does one determine the math model that is to be developed and how are the elements represented? The following discussion is intended to describe the techniques that can be used to develop models using

the features contained in KRASH and the data that are obtained from KRASH. While the information contained herein is directly related to KRASH, it is also applicable to analytical modeling techniques in general.

Included in this report are the following sections:

Section 2 - User's Guide

Section 3 - Math Model Development Procedures

Section 4 - KRASH Data Requirements

Section 5 - Typical Model Arrangements

Section 2 describes the input-output formats and provides illustrative samples of the data. Section 3 presents a general description in which the procedures for setting up a math model using KRASH are outlined. Section 4 describes the input data requirements relative to how the user can obtain and use information with KRASH. Included in this section is background information to help the user more fully understand how KRASH can best be utilized in an analysis. Section 5 presents some typical general aviation airplane model arrangements as represented in KRASH. This section provides the user with an appreciation of the size requirements for different classes of light fixed wing airplanes.

The theory of KRASH is comprehensively described in Reference 1.

SECTION 2

USER'S GUIDE

2.1 INPUT

The input data format is described in detail in this section and is shown in Figure 2-1. Unless otherwise sepcified, all quantities are input in inch, pound, second, and radian units. Two formats are used for the majority of the data; 7E10.0 for fixed-point and scientific-notation input, and I5 for integers. As an example of the former, the number 126.08 can be input in the following ways:

		1	2	6	.	0	8		
		1	2	6	.		8		

	1	.	2	6	0	8		E	2
	1	2	6	0	8	.	E	-	2

Blank columns are treated as zeros. When the E format is used, the exponent must be right justified in the field. With the I5 integer format, the number must be right justified. Sequence numbers in columns 77 through 80 should be used corresponding to those shown in the input format (Figure 2-1) to facilitate deck assembly and changes.

The following coordinate systems (Figure 2-2) are established to facilitate the derivation of equations for the mathematical model. The input data description specify the appropriate coordinate systems to be used.

- Ground Coordinate System. - This is a right-handed coordinate system fixed in the ground with the origin at point 0 in Figure 2-2. The x-axis is positive forward, the y-axis is positive to the right, and the z-axis is positive downward. The xy-plane ($z = 0$) corresponds to the ground surface. The ground coordinate system is considered an inertial coordinate system for writing the dynamic equations of motion.

GENERAL PURPOSE DATA SHEET

LOCKHEED-CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

TITLE:					PAGE	OF
PREPARED BY	DATE	CHECKED BY	DATE	JOB NO / W O	GROUP / EWA	ID / SEQ

1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–65	66–70	ID (73–76)	SEQ (77–80)
TITLE CARD															0001
TITLE CARD															0002
12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	12	0003
NM	NSP	NB	NLB	NNP	NPIN	NUB	NDRI	NOLEO	NACC	MVP	NVCH	NMTL	ND		0004
NVBM	NFBM	NVBMN	NFBMN	NKM	NHI	NPH.	NTOL1	NTOL2	NTOL3	NSC	NIC				0005
NAME		CASE NO.			TRS										0006
NAME		CASE NO.		TSAV1		TSAV2		TSAV3		TSAV4		TSAV5			0007
DP/DT		DT		TMAX		PLOWT		FCUT		RUNMOD					0008
BLANK CARD															0009
NSF	NTF	NDE	NSPD	NED	NS	NRP	NIMP								0010
NMEP	NNEP	NBFP	NBDP	NSTP	NSEP	NEUP	NDRP	NPLT	NPFCT						0011
XGDOT		YGDOT		ZGDOT											0012
PPR		QPR		RPR											0013
PHIPR		THEPR		PSIPR		XGIN		ZGIN		BETA					0014
WGT		XDP		YDP		ZDP		XI		YI		ZI		0101	01NM
MUP	INP	XNPDP		YNPDP		ZNPDP								0201	02NUP
M I	K	XLBAR		XMU		XKE		FPLOW		GFLEX				0301	03NSP
SI		SA		SB		SF		FSPOI		FSPOF		CDAMP		0401	04NSP
M I N	J	AA		XJ		IYY		IZZ		XIQ		Z1	Z2 MC	0501	05NB
MC		EE		GG		STENS		SCOMP		SHEAR				0601	06NMTL
M I N	J	PYI	PZI	PYJ	PZJ	SF35		SF26		SF35J		SF26J		0701	07NPIN
M I N	J	IJUB		DB										0801	08NUB
ALPHAP															0900
M I N	J	EOLEO		FAO		FAA		EXPOLE		YMAX				0901	09NOLEO

Figure 2-1. KRASH Input Format (Sheet 1 of 3)

GENERAL PURPOSE DATA SHEET

LOCKHEED CALIFORNIA COMPANY
A DIVISION OF LOCKHEED AIRCRAFT CORPORATION

TITLE	PREPARED BY	DATE	CHECKED BY	DATE	JOB NO / WO	GROUP / EWA	PAGE / ID	OF / SEQ

1–10	11–20	21–30	31–40	41–50	51–60	61–70	73–76	77–80
M I N J	BOLEO	BROLEO	XKEXT	XKCOMP	FCOUL		1001	10NOLD
DAMPC							1100	
M I N J	$\bar{C}$						1101	11ND
M I N J	L NP	LDP	LDP1				1201	12NCB
XKR_1	KR_1	KR TABLES FOR TYPE 10 OR HIGHER CURVES					1301	13XX
XKR_n	KR_n							
XN	XP	YN	YP	ZN	ZP			1400
I_1 J_1	I_2 J_2	I_3 J_3	I_4 J_4	I_5 J_5	I_6 J_6	I_7 J_7	1401	14XX
I_{1i} I_{2i}	I_{3i} I_{4i}	I_{5i} I_{6i}	I_{7i} I_{8i}				1501	15NVCH
M I N J	VMAX1	VMAX2	VMAX3	VMAX4	VMAX5	VMAX6	1601	16NVBM
M I N J	VMAXN1	VMAXN2	VMAXN3	VMAXN4	VMAXN5	VMAXN6	1701	17NVBM
M I N J	FMAX1	FMAX2	FMAX3	FMAX4	FMAX5	FMAX6	1801	18NFBM
M I N J	FMAXN1	FMAXN2	FMAXN3	FMAXN4	FMAXN5	FMAXN6	1901	19NFBM
I LC	HEX	HEY	HEZ	XYI	YZI	XZI	2001	20NHI
I	PHIDP	THEDP	PSIDP				2101	21NPH
I L	NP						2201	22NACC
T_1	$ACCEL_1$	ACCEL INPUT TIME HISTORY TABLES					2301	23XX
T_n	$ACCEL_n$							
M I N J							2400	24XX
K11	K12	K13	K14	K15	K16			
K21	K22	K23	K24	K25	K26			
K31	K32	K33	K34	K35	K36			
K41	K42	K43	K44	K45	K46			

Figure 2-1. KRASH Input Format (Sheet 2 of 3)

GENERAL PURPOSE DATA SHEET

TITLE

PREPARED BY | DATE | CHECKED BY | DATE | JOB NO. | W.O. | GROUP | EWA | PAGE | OF | ID | SEQ

1–6	7–12	13–18	19–24	25–30	31–36	37–42	43–48	49–54	55–60	61–66	67–72	ID (73–76)	SEQ (77–80)
K51		K52		K53	K54		K55		K56			2400	24XX
K61		K62		K63	K64		K65		K66				
NTPL	NMPTS	ISCLE		XSCALE	YSCALE		POSITION PLOT DATA SET					2501	25NPLT
MNUM1	MNUM2	MNUM3	MNUM4	MNUM5	MNUM6	MNUM7	---			---	MNUM14	2502	25NPLT
I	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9			2601	26NMEP
M	I	NP1	NP2	NP3	NP4	NP5						2701	27NNEP
IJ	BFP1	BFP2	BFP3									2801	28NBFP
IJ	BDP1	BDP2	BDP3									2901	29NBDP
IJ	STP1	STP2	STP3	STP4	STP5							3001	30NSTP
I	M	SEP1	SEP2									3101	31NSEP
IJ	ENG1	ENG2										3201	32NENP
J												3301	33NDRF
END												3400	

FORM 8104-1

Figure 2-1. KRASH Input Format (Sheet 3 of 3)

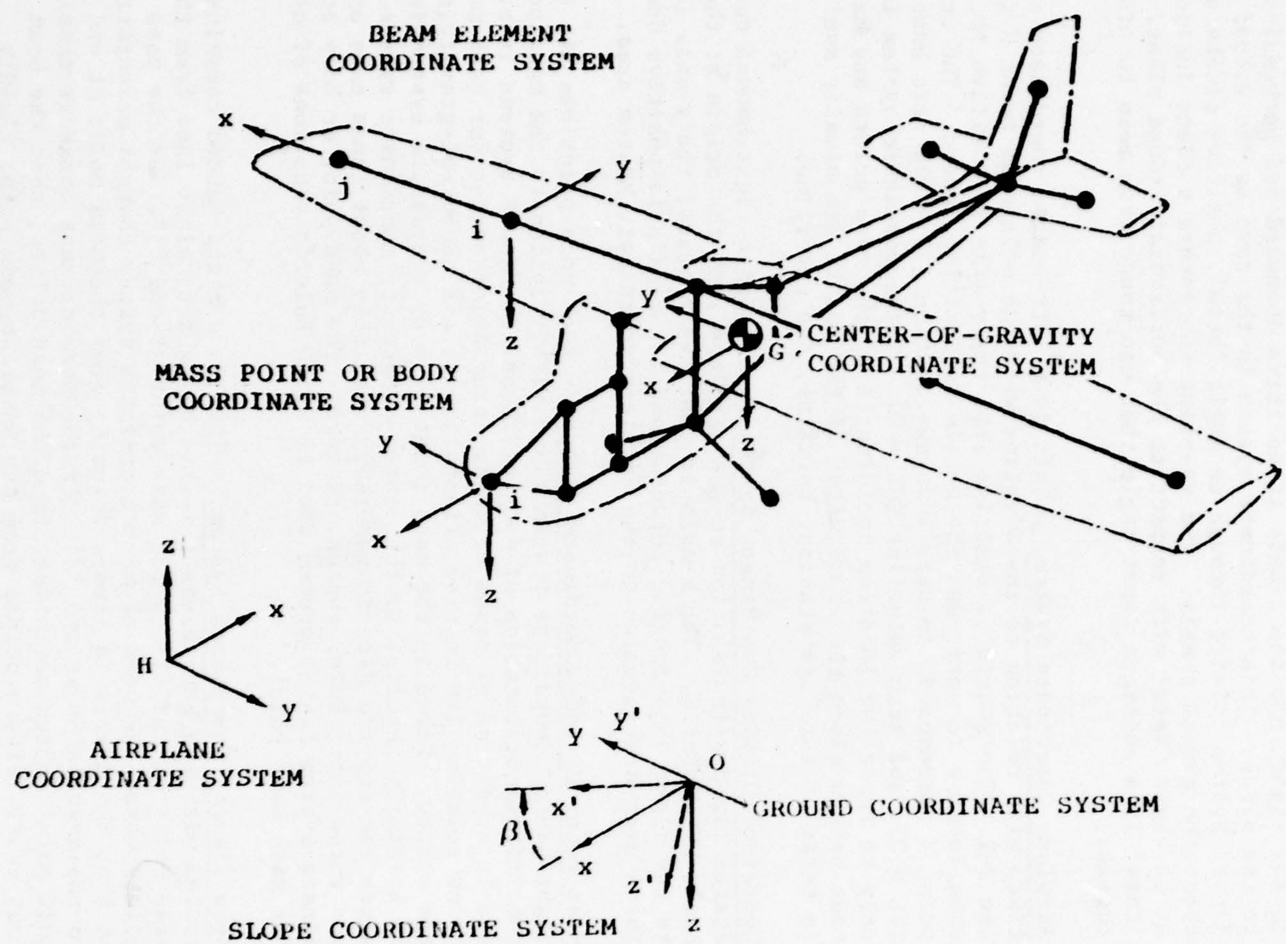


Figure 2-2. KRASH Coordinate Systems

- Slope Coordinate System. - This is a right-handed coordinate system fixed in the ground with the origin at point 0 as shown in Figure 2-2. The x-axis is positive forward up the slope, the y-axis is positive to the right, and the z-axis is positive downward and perpendicular to the slope. This coordinate system is the same as the ground coordinate system rotated through an angle 'beta', positive clockwise about the ground y-axis. The xy-plane represents a plane inclined at an angle 'beta' with respect to the horizontal ground plane. 'Beta' is a constant input angle that can range from zero to ninety degrees.

- Airplane Coordinate System. - This is a left-handed coordinate system fixed with relation to the airplane with the origin at point H in Figure 2-2. The x-axis is positive aft, the y-axis is positive to the left when looking forward, and the z-axis is positive upward. The origin at point H corresponds to zero fuselage station (FS = 0), zero buttline (BL = 0), and zero waterline (WL = 0). This coordinate system is used only to input the location coordinates of the mass points and massless node points since the coordinates of the points are usually available in terms of fuselage station, buttline, and waterline.

- Center-of-Gravity Coordinate System. - This is a right-handed coordinate system fixed with relation to the airplane with the origin at the vehicle CG, point G. The x-axis is positive forward, the y-axis is positive to the right when looking forward, and the z-axis is positive downward. These axes are parallel to the airplane coordinate system axes.

- Mass Point or Body Coordinate System. - Each mass point has its own right-handed coordinate system fixed with relation to the mass point. The initial orientation of each of these coordinate systems is arbitrary and is specified by means of three input Euler angles for each mass point relating its initial orientation to the center-of-gravity coordinate system. Normally the mass point or body coordinate system is taken as initially parallel to the center-of-gravity coordinate system since the inertia data is generally available about these axes and the three input Euler angles are zero. The mass point or body coordinate system is the system used to write Euler's equations of motion for each mass point.

- Beam Element Coordinate System. - This is a right-handed coordinate system with the beam element x-axis along a straight line from the mass point at end 'I' to the mass point at end "j". As the mass points move, the beam element coordinate system changes orientation so that the x-axis is always pointing from the mass point at end "I' to the mass point at end 'J'. If the beam element connects massless node points which are offset from the mass points, then the beam element x-axis always points from the massless node point rigidly attached to the mass point at end 'I' to the massless node point rigidly attached to the mass point at end 'J'.

The beam element y-axis and z-axis are mutually perpendicular. The direction of each is arbitrary and is defined internally within the program. The input data is prepared according to the beam element coordinate systems shown in Figure 2-3 (page 2-29).

The following is a detailed description of all the input data requirements.

41

KRASH INPUT DATA

CARD 0001: TITLE CARD #1

DESCRIPTION: Defines an alphanumeric label which will appear as the first line of heading on each page of KRASH printed output.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8 12345678901234567890123456789012345678901234567890123456789012345678901234567890	
TITLE1	
SUBSTRUCTURE SECTION IMPACT STUDY	0001

FIELD	CONTENTS
Title1	Alphanumeric Character String

REMARKS:

(1) Required data card; however, it may be blank.
(2) Use columns 73-80 to number the input data.
(3) All text material on this card is reproduced at the top of every output page and on every plot.

CARD 0002: TITLE CARD #2

DESCRIPTION: Defines an alphanumeric label which will appear as the second line of heading on each page of KRASH printed output.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8 12345678901234567890123456789012345678901234567890123456789012345678901234567890	
TITLE2	
INITIAL CONDITIONS: 27.5 FPS VERTICAL IMPACT ON RIGID SURFACE	0002

FIELD	CONTENTS
Title2	Alphanumeric Character String

REMARKS:

(1) Required data card; however, it may be blank.
(2) Use columns 73-80 to number the input data.
(3) All text material on this card is reproduced at the top of every output page and on every plot.

KRASH INPUT DATA

CARD 0003: DUMMY CARD

DESCRIPTION: Defines a numeric heading which will appear on each page of the KRASH printout of the input data deck echo.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8 12345678901234567890123456789012345678901234567890123456789012345678901234567890	
DUMMY	
123456789012345678901234567890123456789012345678901234567890123456789012	0003

FIELD	CONTENTS
Dummy	Numeric String

REMARKS:
(1) Required data card; however, it may be blank.
(2) Intent of this data card is to aid the user in verifying the field placement of the input data.
(3) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0004: KRASH MODEL SIZE PARAMETERS

DESCRIPTION: Defines the sizes of the various input parameter data sets for the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

NM	NSP	NB	NLB	NNP	NPIN	NUB	NDRI	NOLEO	NACC	MVP	NVCH	NMTL	ND	X	
16	10	32	2	6	0	4	0	0	0	0	0	0	1		0004

FIELD	CONTENTS
NM	Number of Mass Points Per 0100-Series Cards (Maximum Allowed is 80)
NSP	Number of External Crushing Springs Per 0300-Series Cards (Maximum Allowed is 40)
NB	Number of Beam Elements Per 0500-Series Cards (Maximum Allowed is 150)
NLB	Number of Beam Element Nonlinear Degrees-of-Freedom Per 1200-Series Cards (Maximum Allowed is 180)
NNP	Number of Massless Node Points Per 0200-Series Cards (Maximum Allowed is 50)
NPIN	Number of Beam Elements Having at Least One Degree-of-Freedom Pinned Per 0700-Series Card (Maximum Allowed is 150)
NUB	Number of Axially Unsymmetric Beam Elements Per 0800-Series Cards (Maximum Allowed is 150)
NDRI	Number of DRI Beam Elements Per 1401-Series Cards (Maximum Allowed is 150)
NOLEO	Number of Shock Strut Elements Per 900 and 1000-Series Cards (Maximum Allowed is 20)
NACC	Number of Enforced Acceleration Time History Tables Per 2300-Series Cards (Maximum Allowed is a Combination of 300 Mass and Time Points, For Example 50 Masses Each With 6 Associated Times)
MVP	Reference Mass Point For Volume Penetration Calculations Per 1400-Series Cards Maximum Allowed is 1)
NVCH	Number of Volumes For Occupiable Volume Change Calculations Per 1500-Series Cards (Maximum Allowed is 5)
NMTL	Number of Non-Standard Beam Element Materials Per 0600-Series Cards (Maximum Allowed is 10)
ND	Number of Beam Elements With Non-Standard Damping Ratios Per 1100-Series Cards (Maximum Allowed is 150)

REMARKS:

(1) Required data card.
(2) All entries are right justified integers.
(3) 'NM', 'NSP', and 'NB' must be nonzero.
(4) Blank entries are read as zero.
(5) See Table 2-1 for a summary of model size parameters.
(6) Format for this card is 14I5.
(7) Use columns 73-80 to number the input data.

TABLE 2-1. PROGRAM SIZING CONSTANTS

CONSTANT	MAXIMUM VALUE	DESCRIPTION
NM	80	NUMBER OF MASSES
NSP	40	NUMBER OF EXTERNAL SPRINGS
NB	150	NUMBER OF INTERNAL BEAMS
NLB	180	NUMBER OF NONLINEAR BEAM-DIRECTION COMBINATIONS (KR TABLES)
NHI	80	NUMBER OF MASSES HAVING NON-ZERO He_{x_i}, He_{y_i}, He_{z_i}, I_{xy_i}, I_{yz_i}, I_{xz_i}, OR ℓc_i
MVP	–	REFERENCE MASS NUMBER FOR VOLUME PENETRATION CALCULATIONS
NVCH	5	NUMBER OF VOLUMES FOR OCCUPIABLE VOLUME CHANGE CALCULATIONS
NDRI	150	NUMBER OF DRI BEAM ELEMENTS
NMTL	10	NUMBER OF NON-STANDARD BEAM MATERIALS
NACC	300	NUMBER OF INPUT ACCELERATION TIME-HISTORY POINTS
NVBM	150	NUMBER OF INTERNAL BEAMS HAVING NON-STANDARD MAXIMUM POSITIVE (NVBM) OR NEGATIVE (NVBMN) DEFLECTIONS FOR BEAM RUPTURE. STANDARD VALUE = 100 (inches OF DEFLECTION AND radians OF ROTATION)
NVBMN	150	
NFBM	150	NUMBER OF INTERNAL BEAMS HAVING NON-STANDARD MAXIMUM POSITIVE (NFBM) OR NEGATIVE (NFBMN) FORCES FOR BEAM RUPTURE. STANDARD VALUE = 1E10
NFBMN	150	
NPH	80	NUMBER OF MASSES HAVING NON-ZERO EULER ANGLES ϕ_i", θ_i", ψ_i"
ND	150	NUMBER OF INTERNAL BEAMS HAVING DAMPING RATIOS DIFFERENT FROM THAT SPECIFIED ON CARD 1100
NKM	150	NUMBER OF INTERNAL BEAMS FOR WHICH THE FULL 6 x 6 STIFFNESS MATRIX IS DIRECTLY INPUT
NPIN	150	NUMBER OF INTERNAL BEAMS HAVING OTHER THAN FIXED-FIXED END CONDITIONS
NNP	50	NUMBER OF MASSLESS NODE POINTS
NUB	150	NUMBER OF UNSYMMETRICAL BEAMS
NOLEO	20	NUMBER OF SHOCK STRUTS

KRASH INPUT DATA

CARD 0005: KRASH MODEL SIZE PARAMETERS AND CALCULATION FLAGS

DESCRIPTION: Defines the sizes of the various input parameter data sets for the KRASH model and provides for beam element stress and/or failure data calculations.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890 (cont.)															
NVBM	NFBM	NVBMN	NFBMN	NKM	NHI	NPH	NTOL1	NTOL2	NTOL3	NSC	NIC	X	X	X		
0	0	0	0	0	0	0	10	50	100	0	0					0005

FIELD	CONTENTS
NVBM	Number of Beam Elements Having Non-Standard Rupture Positive Deflections Per 1600-Series Cards (Maximum Allowed is 150)
NFBM	Number of Beam Elements Having Non-Standard Rupture Positive Forces Per 1700-Series Card (Maximum Allowed is 150)
NVBMN	Number of Beam Elements Having Non-Standard Rupture Negative Deflections Per 1800-Series Card (Maximum Allowed is 150)
NFBMN	Number of Beam Elements Having Non-Standard Rupture Negative Forces Per 1900-Series Cards (Maximum Allowed is 150)
NKM	Number of Beam Elements For Which 6 x 6 Stiffness Matrix is Directly Input Per 2400 Series Cards (Maximum Allowed is 150)
NHI	Number of Mass Points Having Nonzero Aerodynamic Lift Constant, Angular Momenta, or Cross Products of Inertia Per 2000-Series Card (Maximum Allowed is 80)
NPH	Number of Mass Points Having Nonzero Euler Angles For Rotating the Mass Point or Body Coordinate System Relative to The Center-of-Gravity Coordinate System Per 2100-Series Cards (Maximum Allowed is 80)
NTOL1	Percent Allowable Total Energy Growth Above 100 Percent (Default Value is One (1) Percent)
NTOL2	Percent Allowable Individual Negative Strain, Damping, Crushing and Friction Terms of Respective Totals (Default Value is Ten (10) Percent)
NTOL3	Percent Allowable Individual Mass Energy Deviation Above Zero Percent (Default Value is Thirty (30) Percent
NSC	Flag For Beam Element Stress Calculation: 0 = No 1 = Yes
NIC	Flag For Preliminary Beam Element Failure Load and Deflection Calculations: 0 = No 1 = Yes

REMARKS:

(1) Required data card; however it may be blank.
(2) All entries are right justified integers.
(3) Blank entries are read as zero.
(4) If any of the allowable errors in energy are exceeded, the analysis terminates automatically at that time, and summary tables and printer plots are generated.
(5) Default values for NVBM and NVBMN are 100 inches or radians. Default values for NFBM and NFBMN are 1E10, lbs or in-lbs.
(6) See Table 2-1 for a summary of model size parameters.
(7) It is recommended that NIC = 1 be used each time if complete beam properties are input (Ø500-series cards).
(8) Format for this card is 12I5.
(9) Use columns 73-80 to number the input data.

CARD 0006: RESTART CONTROL PARAMETERS

DESCRIPTION: Defines the identifiers of a previously checkpointed KRASH case and the simulation time from which the KRASH analysis will be restarted.

FORMAT AND EXAMPLE:

NAME		CASENO	TRS						
OLEO		1	40						0006

FIELD CONTENTS

FIELD	CONTENTS
Name	Alphanumeric Identifier of Checkpointed Case (Maximum of Eight Characters, Left Justified)
CASENO	Numeric Identifier of Checkpointed Case
TRS	Restart Time – Milliseconds

REMARKS:

(1) Required data card, however, it may be blank.
(2) All numeric entries are right justified integers.
(3) Previously checkpointed case must be resident on mag tape and be accessed via JCL.
(4) Restart time must be included in the KRASH analysis of the previously checkpointed case.
(5) Only nonblank when using restart capability to initiate from a preceding analysis that has been saved.
(6) Use columns 73-80 to number the input data.
(7) Format for this card is A8, 2X, 6I10.

KRASH INPUT DATA

CARD 0007: CHECKPOINT CONTROL PARAMETERS

DESCRIPTION: Defines indentifiers and simulation times for the current KRASH case to checkpoint the analytical results for future restarts.

FORMAT AND EXAMPLE:

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

NAME	X	CASENO	TSAV1	TSAV2	TSAV3	TSAV4	TSAV5	X	
OLEO		2	40	80	100	120	150		0007

FIELD	CONTENTS
Name	Alphanumeric Identifier (Maximum of Eight Characters, Left Justified)
CASENO	Numeric Identifier
TSAV1	Analysis Times at Which Results Will be Saved – Milliseconds

REMARKS:

(1) Required data card; however, it may be blank.
(2) All numeric entries are right justified integers.
(3) JCL must provide mag tape on which results will be saved.
(4) Only nonblank when data is to be saved. A maximum of five times can be saved per analysis.
(5) Format for this card is A8, 2X, 6I10.0.
(6) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0008: PARAMETERS FOR NUMERICAL INTEGRATION, PLOWING FORCE, ACCELERATION FILTER, AND KRASH EXECUTION MODE

DESCRIPTION: Defines print control, numerical integration time step, analysis time, plowing force time, acceleration filter cutoff frequency, and KRASH execution mode (airplane model and impact condition symmetry).

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8
DP/DT	DT	TMAX	PLOWT	FCUT	RUNMOD			
100	0.00001	0.120	0.0	100.0	1.0			0008

FIELD	CONTENTS
DP/DT	Number of Numerical Integration Time Steps For Which Printout of Results Will be Suppressed. Right Justified
DT	Fixed Time Step For Numerical Integration – Seconds
TMAX	Maximum Analysis Time – Seconds
PLOWT	Analysis Time at Which Plowing Forces Cease – Seconds
FCUT	Cutoff Frequency of First-Order Filter Applied to Mass Point Translational Accelerations – Hertz (E10.0 Format)
RUNMOD	Flag to Control the Mode of Program Execution as Follows:

RUNMOD	INPUT DATA SET	DATA SET ANALYZED	AIRPLANE MODEL	IMPACT CONDITIONS
0.	Full Airplane	Full Airplane	Unsymmetrical	Unsymmetrical
1.	Half Airplane	Half Airplane	Symmetrical	Symmetrical
2.	Half Airplane	Full Airplane	Symmetrical	Unsymmetrical

REMARKS:

(1) Required data card.
(2) 'DP/DT', 'DT', 'TMAX', and 'RUNMOD' are required inputs.
(3) Blank entries are read as zero.
(4) Entries requiring scientific notation (X.XEXX) should be right justified.
(5) Format for this card is I10, 5E10.0.
(6) Suitable values for 'DT' range from 0.00001 to 0.001 seconds. A rule of thumb for selecting a final integration value is the following:
$$DT \leq 0.01 \text{ Max. Computed Beam Frequency (Hz)}$$
(7) Nonzero plowing forces act from time = 0 to time = 'PLOWT'. For time > 'PLOWT' the plowing forces are set to zero.
(8) Suitable values for 'FCUT' range from fifty to eighty-five percent of the actual test filter cutoff frequency. Eighty-five percent is commonly used.
(9) Use columns 73-80 to number the input data.

CARD 0009: VARIABLE INTEGRATION PARAMETERS

DESCRIPTION: Define parameters for numerical integration with variable time step.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8 12345678901234567890123456789012345678901234567890123456789012345678901234567890								
IVAR	EL	EU	RATMIN	RATMAX				
1	0.01	0.10	0.6	2.0				0009

FIELD CONTENTS

IVAR — Flag For Type of Numerical Integration With Variable Time Step as Follows (Right Justified Integer):

IVAR	TYPE OF NUMERICAL INTEGRATION WITH VARIABLE TIME STEP
0	None
1	Tolerance Based on Six Linear and Angular Velocities of Each Mass Point
2	Tolerance Based on Energy

EL — Maximum Tolerance
EU — Minimum Tolerance
RATMIN — Integration Time Step Factor if Tolerance > 'EU'
RATMAX — Integration Time Step Factor if Tolerance < 'EL'

REMARKS:
(1) Required data card, but it should be blank as the variable integration algorithm is not currently operational.
(2) Blank entries are read as zero.
(3) Format for this card is I10, 4E10.0.
(4) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0010: PRINT OUTPUT CONTROL

DESCRIPTION: Defines flags to control the printout of results, KRASH model size parameters, and allowable errors in energy for terminating the analysis.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8												
12345	67890	12345	67890	12345	67890	12345	67890	1234567890	1234567890	1234567890	12	34567890
NSF	NTF	NDE	NSPD	NED	NS	NRP	NIMP					
1	1	1	1	1	1	1	1					0010

FIELD	CONTENTS
NSF	Flag For Printout of Beam Element Strain Forces
NTF	Flag For Printout of Beam Element Total Forces – Strain and Damping
NDE	Flag For Printout of Beam Element Deflections
NSPD	Flag For Printout of External Crushing Spring Loads and Deflections
NED	Flag For Printout of Energy Distribution Per Mass Point, Beam Element, and External Crushing Spring
NS	Flag For Printout of Beam Element Stresses
NRP	Flag For Printout of Mass Point Displacement, Velocity, and Accelerations
NIMP	Flag For Printout of Mass Impulses

REMARKS:

(1) Required data card; however, it may be blank.
(2) All entries are right justified integers.
(3) Blank entries are read as zero.
(4) Print control flags: 0 = No, 1 = Yes.
(5) Format for this card is 8I5.
(6) Use columns 73-80 to number the input data.

31

KRASH INPUT DATA

CARD 0011: PRINTER PLOT CONTROL PARAMETERS

DESCRIPTION: Defines the type and number of time history printer plots and defines the number of mass point position (structure deformation) printer plots.

FORMAT AND EXAMPLE:

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

NMEP	NNEP	NBFP	NBDP	NSTP	NSEP	NENP	NDRP	NPLT	NPFCT				
21	0	3	0	0	0	2	1	2	20				0011

FIELD	CONTENTS
NMEP	Number of Mass Points Having Time History Printer Plots Per 2600-Series Cards
NNEP	Number of Massless Node Points Having Time History Printer Plots Per 2700-Series Cards
NBFP	Number of Beam Elements Having Load Time History Printer Plots Per 2800-Series Cards
NBDP	Number of Beam Elements Having Deflection Time History Printer Plots Per 2900-Series Cards
NSTP	Number of Beam Elements Having Stress Time History Printer Plots Per 3000-Series Cards
NSEP	Number of External Crushing Springs Having Time History Printer Plots Per 3100-Series Cards
NENP	Number of Beam Elements Having Strain and/or Damping Energy Time History Printer Plots Per 3200-Series Cards
NDRP	Number of DRI Mass Points Having Time History Printer Plots Per 3300-Series Cards
NPLT	Number of Mass Point Position (Structure Deformation) Printer Plots Per 2500-Series Cards
NPFCT	Print Time Factor For Which Mass Point Position (Structure Deformation) Plots Are Generated

REMARKS:

(1) Required data card; however, it may be blank.
(2) All entries are right justified integers.
(3) Blank entries are read as zero.
(4) Blank or zero entries do not generate printer plots.
(5) Mass position plots occur at time = 0, and at intervals equal to NPFCT x DP/DT x DT.
(6) Format for this card is 10I5.
(7) Use columns 73-80 to number the input data.

CARD 0012: INITIAL AIRPLANE LINEAR VELOCITIES

DESCRIPTION: Defines the initial airplane linear velocity components with respect to the ground coordinate system.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	7 34567890	8
XGDOT	YGDOT	ZGDOT							
0.0	0.0	360.0						0012	

FIELD	CONTENTS
XGDOT	Initial Fore-and-Aft Velocity of Airplane, Positive Forward
YGDOT	Initial Lateral Velocity of Airplane, Positive Right
ZGDOT	Initial Vertical Velocity of Airplane, Positive Down

REMARKS:

(1) Required data cards; however, it may be blank.
(2) Velocity units are inches per second.
(3) Blank entries are read as zero.
(4) Entries requiring scientific notation (X.XEXX) should be right justified.
(5) Format for this card is 3E10.0.
(6) Use columns 73-80 to number the input data.

CARD 0013: INITIAL AIRPLANE ANGULAR VELOCITIES

DESCRIPTION: Defines the initial airplane angular velocity components with respect to the ground coordinate system.

FORMAT AND EXAMPLE:

0 1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
PPR	QPR	RPR					
0.0	0.0	0.012					0013

FIELD	CONTENTS
PPR	Initial Airplane Roll Velocity, Positive Right Wing Down
QPR	Initial Airplane Pitch Velocity, Positive Nose Up
RPR	Initial Airplane Yaw Velocity, Positive Nose Right

REMARKS:
(1) Required data card; however, it may be blank.
(2) Angular velocity units are radians per second.
(3) Blank entries are read as zero.
(4) Entries requiring scientific notation (X.XEXX) should be right justified.
(5) Format for this card is 3E10.0.
(6) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0014: MISCELLANEOUS AIRPLANE INITIAL CONDITIONS

DESCRIPTION: Defines the initial airplane attitude Euler angles and the initial airplane linear position with respect to the ground coordinate system and defines the ground plane slope angle.

FORMAT AND EXAMPLE:

1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	12	3456	7890
PHIPR	THEPR	PSIPR	XGIN	ZGIN	BETA			
0.0	0.001	0.0	0.0	0.0	45.0			0014

FIELD CONTENTS

PHIPR Initial Airplane Roll Euler Angle, Positive Right Wind Down – Radians
THEPR Initial Airplane Pitch Euler Angle, Positive Nose Up – Radians
PSIPR Initial Airplane Yaw Euler Angle, Positive Nose Right – Radians
XGIN Fore-and-Aft Distance of Airplane Initial CG Position Relative to the Basic Position Calculated in the Initial Condition Subroutine, Positive Aft – Inches
ZGIN Vertical Distance of Airplane Initial CG Position Relative to the Basic Position Calculated in the Initial Condition Subroutine, Positive Up – Inches
BETA Ground Plane Slope Angle, Positive Up – Degrees

REMARKS:
(1) Required data card; however, it may be blank.
(2) Blank entries are read as zero.
(3) Normally, 'XGIN' and 'ZGIN' are input as zero and the KRASH initial conditions subroutine positions the airplane relative to ground.
(4) If it is desired to have the airplane impact only on the slope and not on the horizontal ground, a large value of ZGIN may be input (1000 inches). This will move the airplane upward ZGIN above the horizontal ground, and simultaneously move it forward so that it is almost contacting the slope. The normal initial position for the airplane is wedged into the juncture of the horizontal ground and the slope as explained in Volume I, Section 1.3.15.
(5) Values of 'BETA' range from zero to ninety degrees (horizontal to vertical impact surfaces).
(6) Entries requiring scientific notation (X.XEXX) should be right justified.
(7) Formats for this card is 6E10.0.
(8) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 0101-01NM: MASS POINT DATA

DESCRIPTION: Defines the weight, location coordinates, and mass moments of inertia for each of the mass points in the KRASH model.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	345	67890
WGT	XDP	YDP	ZDP	XI	YI	ZI	X		
103.0	50 0	20.0	33.0	12.5	3.7	12.5			0101

FIELD	CONTENTS
WGT	Weight – Pounds
XDP	Fuselage Station Coordinate, Positive Aft – Inches
YDP	Buttline Coordinate, Positive Left – Inches
ZDP	Waterline Coordinate, Positive Up – Inches
XI	Roll Mass Moment of Inertia – Inch * Pound * Second**2
YI	Pitch Mass Moment of Inertia – Inch * Pound * Second**2
ZI	Yaw Mass Moment of Inertia – Inch * Pound * Second**2

REMARKS:

(1) 'NM' on card 0004 specifies the number of these cards for input.
(2) The order of these cards determines the mass point number.
(3) Blank entries are read as zero.
(4) The location coordinates are defined in a left-handed coordinate system.
(5) At least one of the three mass moments of inertia must be nonzero.
(6) Mass moment of inertia cross products may be defined on the 2000-series of cards.
(7) Entries requiring scientific notation (X.XEXX) should be right justified.
(8) Formats for this card is 7E10.0.
(9) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 0201-02NNP: MASSLESS NODE POINT DATA

DESCRIPTION: Defines for each of the massless node points in the KRASH model the location coordinates and the mass point number to which each is rigidly attached.

FORMAT AND EXAMPLE:

0 1234567890	1 12345	67890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	34567890 8
MNP	INP	XNPDP	YNPDP	ZNPDP					
1	12	10.0	-12.0	33.0					0201

FIELD CONTENTS

MNP Massless Node Point Number (Right Justified Integer)
INP Mass Point Number (Right Justified Integer)
XNPDP Fuselage Station Coordinate, Positive Aft – Inches
YNPDP Buttline Coordinate, Positive Left – Inches
ZNPDP Waterline Coordinate, Positive Up – Inches

REMARKS:

(1) Optional data card(s).
(2) 'NNP' on card 0004 specifies the number of these cards for input.
(3) 'MNP' and 'INP' must be nonzero.
(4) Blank entries are read as zero.
(5) The massless node point number is determined by taking each mass point and numbering the node points attached to it 1, 2, 3, . . . etc. There is no limit on the number of node points that may be connected to a single mass point.
(6) The location coordinates are defined in a left-handed coordinate system.
(7) User should not place a node point on the center line for a RUNMOD = 2 condition. Program will not generate a connection across this point. User can place node point slightly off center, if necessary.
(8) Generally used to model regions wherein rigid connections exist (i.e., seat, engine) or where multiple behavior is being represented by different elements.
(9) Entries requiring scientific notation (X.XEXX) must be right justified.
(10) Format for this card is 2I5, 3E10.0.
(11) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 0301-03NSP: EXTERNAL CRUSHING SPRING PARAMETERS

DESCRIPTION: Defines the attach point, degree-of-freedom, length, ground coefficient of friction, bottoming out spring rate, plowing force, and ground flexibility for each of the external crushing springs in the KRASH model.

FORMAT AND EXAMPLE:

0		1	2	3	4	5	6	7		8
12	345	67890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890		1234567890
M	I	K	XLBAR	XMU	XKE	FPLOW	GFLEX			
	11	3	10.0	0.3	20000.0	0.0	0.0			0301

FIELD	CONTENTS
M	Massless Node Point Number (Right Justified Integer)
I	Mass Point Number (Right Justified Integer)
K	Degree-of-Freedom in Which External Crushing Spring Acts Where 1, 2, 3 Corresponds to the X, Y, Z Directions in the Mass Point or Body Coordinate System (Right Justified Integer)
XLBAR	Free Length of Spring Either Positive or Negative in the Mass Point or Body Coordinate System – Inches
XMU	Impact Surface Coefficient of Friction. Values of Between 0.35 to 0.60 are Appropriate For Structure to Ground Contact.
XKE	Bottoming Out Spring Rate – Pounds Per Inch
FPLOW	Plowing Force – Pounds
GFLEX	Impact Surface Flexibility – Inches Per Pound

REMARKS:

(1) 'NSP' on card 0004 specifies the number of these cards for input.
(2) Blank entries are read as zero.
(3) At least one external crushing spring is required.
(4) The free length of the external crushing spring is arbitrary; however, the value generally represents the actual depth of the crushable structure.
(5) A value of zero for the impact surface flexibility (GFLEX) represents a rigid surface. A flexibility value of 0.00036 in/lb is an approximate representation in KRASH for soil having a CBR $\simeq 4$ and moisture content of ≈ 30 percent.
(6) Entries requiring scientific notation (X.XEXX) must be right justified.
(7) Format for this card is I2, I3, I5, 5E10.0.
(8) Use columns 73-80 to number the input data.

CARDS 0401-04NSP: EXTERNAL CRUSHING SPRING LOAD-DEFLECTION AND DAMPING PARAMETERS

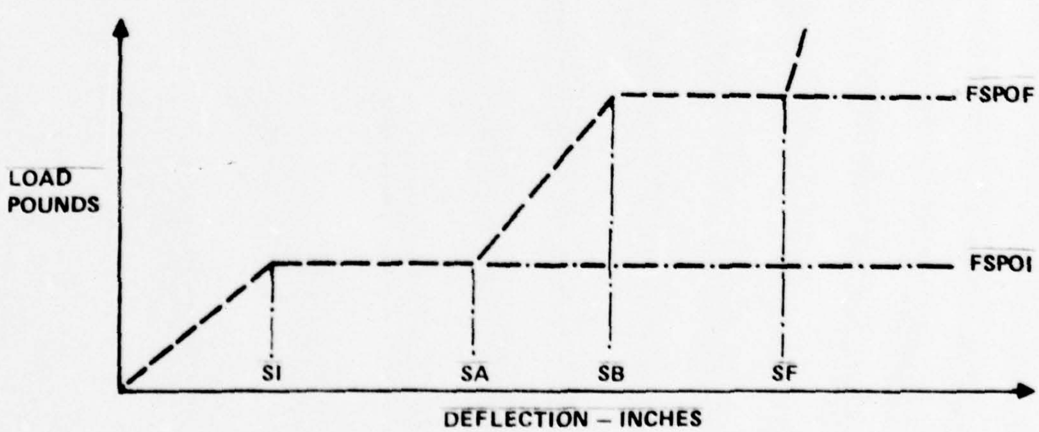
DESCRIPTION: Defines four deflection points, two load values and one damping value for each external crushing spring in the KRASH model.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	34567890
SI	SA	SB	SF	FSPOI	FSPDF	CDAMP	X	
0.1	1.0	3.5	5.0	10000.0	25000.0	.08		0401

FIELD	CONTENTS
SI	Deflection Point at Which First Linear Region Ends and First Nonlinear Region Begins – Inches
SA	Deflection Point at Which First Nonlinear Region Ends and Second Linear Region Begins – Inches
SB	Deflection Point at Which Second Linear Region Ends and Second Nonlinear Region Begins – Inches
SF	Deflection Point at Which Second Nonlinear Region Ends and Linear Bottoming Out Begins – Inches
FSPOI	Constant Load Between Deflection Points SI and SA – Pounds
FSPOF	Constant Load Between Deflection Points SB and SF – Pounds
CDAMP	Critical Damping Value. Acceptable Range is .02 to .10

REMARKS:
(1) 'NSP' on card 0004 specifies the number of these cards for input.
(2) These load-deflection cards must be ordered to correspond with the 0300-series cards of external crushing spring data.
(3) The general shape of the load-deflection curve is as follows:



KRASH INPUT DATA

CARDS 0401-04NSP: EXTERNAL CRUSHING SPRING LOAD-DEFLECTION AND DAMPING PARAMETERS (Continued)

(4) External spring damping in program KRASH is computed as:

$$2 * \text{CDAMP} * \sqrt{(\text{FSPOI/SI}) / \text{WGT} * 386.4}$$

(5) Entries requiring scientific notation (X.XEXX) should be right justified.
(6) Format for this card is 7E10.0.
(7) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 0501-05NB BEAM ELEMENT PROPERTIES

DESCRIPTION: Defines the end points and cross-sectional properties for each beam element in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J	AA	XJ	IYY	IZZ	XIQ	Z1	Z2	MC	
	2	1	5	0.5	0.0	3.67	1.54	0.0	0.0	0.0	4	0501

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number at End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
AA	Cross-Sectional Area – Inches**2.
XJ	Torsional Stiffness Inertia – Inches**4
IYY	Cross-Sectional Area Moment of Inertia About Beam Element Y-Axis For Bending In X-Z Plane – Inches**4
IZZ	Cross-Sectional Area Moment Of Inertia About Beam Element Z-Axis For Bending In X-Y Plane – Inches**4
XIQ	Cross-Sectional Shape Factor Relating Torsional Shear Stress To The Applied Moment – 1/Inches**3
Z1	Distance From The Neutral Axis To The Extreme Fibers In The Beam Element Z-Direction – Inches
Z2	Distance From The Neutral Axis To The Extreme Fibers In The Beam Element Y-Direction – Inches
MC	Material Code Number (Right Justified Integer)

REMARKS:
(1) "NB" on card 0004 specifies the number of these cards for input.
(2) Blank entries are read as zero.
(3) At least one beam element must be defined.
(4) The mass point number at end "I" must be less than the mass point number at end "J".
(5) The order of these data cards determines the beam element number.
(6) If "XJ" is input as zero, KRASH will automatically compute a value for "XJ" as the sum of "IYY" and "IZZ".
(7) The beam element coordinate system depends on the geometric orientation as shown in Figure 2-3.
(8) "XIQ", "Z1", and "Z2" are used only for stress calculations (See Section 1.3.17 in Volume I).
(9) The torsional stress parameter "XIQ" is equal to the shape factor "1/Q" used in Roark's *formulas for stress and strain* (Reference 4).
(10) KRASH has ten standard materials internally defined as shown in Table 2-2.
(11) Entries requiring scientific notation (X.XEXX) should be right jutsified.
(12) Format for this card is 2(I2, I3), 5E10.0, 2F5.0, I2.
(13) Use columns 73-80 to number the input data.

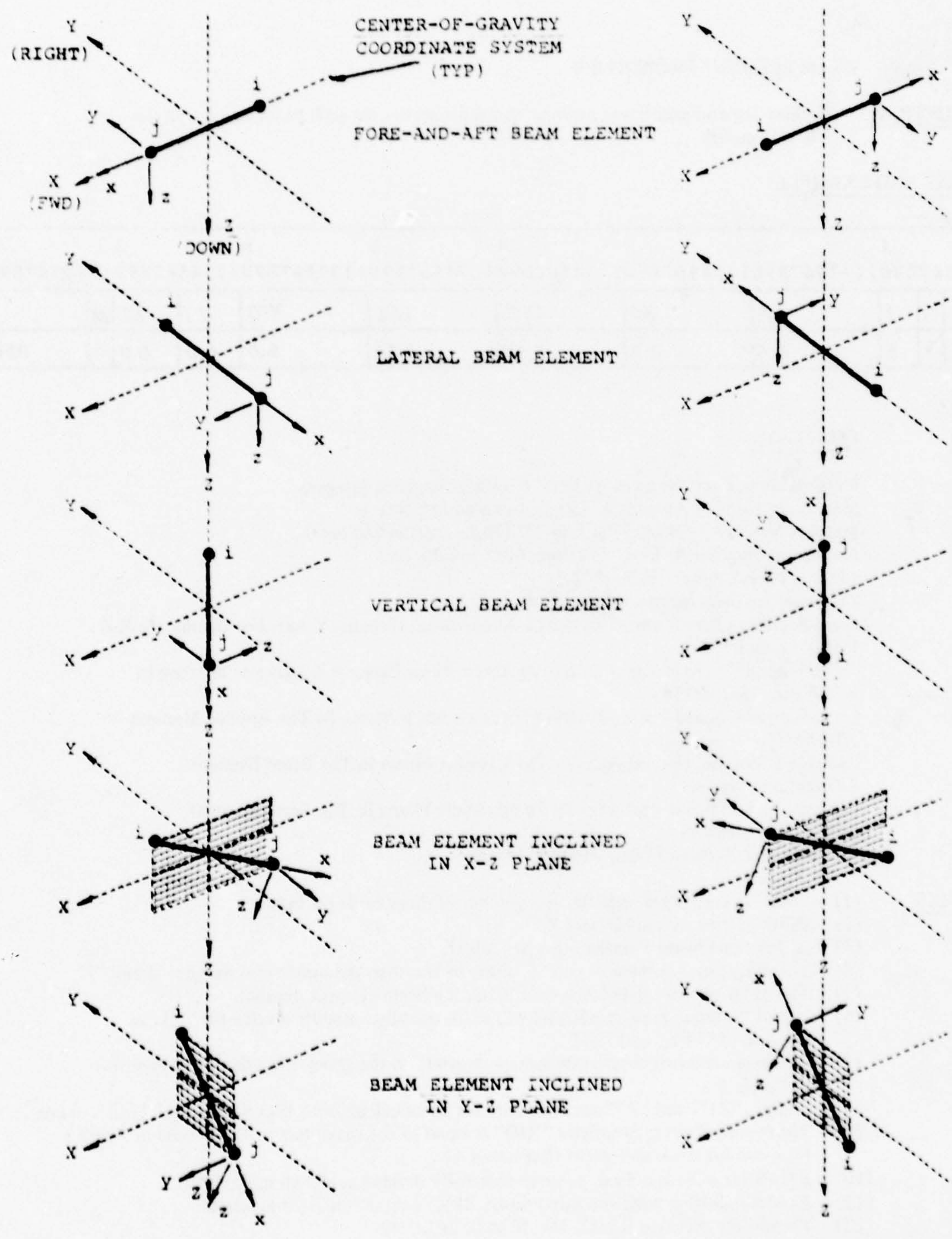


Figure 2-3. Beam Element Coordinate System Orientations

TABLE 2-2. STANDARD MATERIAL PROPERTIES

MC	MATERIAL	MODULUS OF ELASTICITY (PSI)	MODULUS OF RIGIDITY (PSI)	TENSILE STRESS (PSI)	COMPRESSIVE STRESS (PSI)	SHEAR STRESS (PSI)
1	4130 STEEL	30.0E5	11.0E6	75000	75000	37500
2	6150H STEEL	30.0E6	11.0E6	105000	205000	30000
3	300–SERIES STAINLESS STEEL	23.0E6	12.5E6	70000	46000	36000
4	2024–T3 ALUMINUM	10.5E6	4.0E6	47000	39000	22000
5	6061-T3 ALUMINUM	10.0E6	3.8E6	35000	34000	17000
6	8195–T4 CAST ALUMINUM	10.0E6	3.8E6	16000	16000	17000
7	LOW MODULUS MATERIAL	1.0E6	0.3E6	16000	16000	17000
8	ZERO TORSION MATERIAL	1.0E6	0.0	16000	16000	17000
9	DRI SPINE (MAN)	1.0E6	0.3E6	16000	16000	17000
10	DRI SPINE (DRI)	1.0E6	0.3E6	16000	16000	17000

KRASH INPUT DATA

CARDS 0601–
06NMTL: NON-STANDARD MATERIAL PROPERTIES

DESCRIPTION: Defines non-standard material properties for beam elements in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

MC	╳	EE	GG	STENS	SCOMP	SHEAR	╳	╳	
11		10.3E06	3.9E06	35000.0	34000.0	17000.0			0601

FIELD	CONTENTS
MC	Material Code Number, MC = 11-20 (Right Justified Integer)
EE	Modulus Of Elasticity – Pounds Per Inch**2
GG	Modulus Of Rigidity – Pounds Per Inch**2
STENS	Tensile Yield Stress – Pounds Per Inch**2
SCUMP	Compressive Yield Stress – Pounds Per Inch**2
SHEAR	Shear Stress – Pounds Per Inch**2

REMARKS

(1) Optional data card(s).
(2) "NMTL" on card 0004 specifies the number of these cards for input.
(3) Blank entries are read as zero.
(4) The yield stress properties are required when stress calculations are desired.
(5) The standard materials available in KRASH are listed in Table 2-2.
(6) Entries requiring scientific notation (X.XEXX) should be right justified.
(7) Format for this card is I5, 5X, 5E10.0.
(8) Use Columns 73-80 to number the input data.

CARDS 0701
07NPIN: **BEAM ELEMENT PINNED END CONDITIONS**

DESCRIPTION: Defines the end points and the degrees-of-freedom for the beam elements with pinned end conditions in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
1234567890123456789012345678901234567890123456789012345678901234567890123456789 0

M	I	N	J	PYI	PZI	PYJ	PZJ	SF35	SF26	SF35J	SF26J	☒	
	2	6	0	0	1	0	1.0	1.5	1.2		1.0		0701

FIELD	CONTENTS
M	Massless Node Point Number At End "I"
I	Mass Point Number At End "I"
N	Massless Node Point Number At End "J"
J	Mass Point Number At End "J"
PYI	Pin Flag For Bending Moment About Beam Element Y-Axis At End "I"
PZI	Pin Flag For Bending Moment About Beam Element Z-Axis At End "I"
PYJ	Pin Flag For Bending Moment About Beam Element Y-Axis At End "J"
PZJ	Pin Flag For Bending Moment About Beam Element Z-Axis At End "J"
SF35	Beam Shape Factor At End "I" About Beam Y-Axis
SF26	Beam Shape Factor At End "I", About Beam Z-Axis
SF35J	Beam Shape Factor At End "J" About Beam Y-Axis
SF26J	Beam Shape Factor At End "J" About Beam Z-Axis

REMARKS:

(1) Optional data card(s).
(2) "NPIN" on card 0004 specifies the number of these cards for input.
(3) The pin flags are defined as follows:
0 = Fixed
1 = Pinned
(4) Blank entries are read as zero.
(5) All entries except SF26, SF35, SF26J and SF35J are right justified integers. SF26, SF35, SF26J and SF35J are E10.0 format.
(6) The beam element Y- and Z-axis directions depend on the beam element geometric orientation as shown in Figure 2-3.
(7) Bending moments about the beam element Y- and Z-axes correspond to bending moments in the beam element X-Z and X-Y planes, respectively, as outlined in Table 2-3.
(8) All entries requiring scientific notation (X.XEXX) should be right justified.
(9) Format for this card is 2 (I2, I3), 4I5, 4E10.0.
(10) Beam shape factors SF26 and SF35, SF26J, and SF35J can be obtained from Table 2-4, and Reference 14.
(11) SF26, and/or SF35 values are required for representation of plastic hinge at beam end I.
(12) SF26J and/or SF35J values are required for representation of plastic hinge at beam end J.

NOTE: The end fixity card is used:

(a) to pin one or both ends of a beam

If a beam end is to be pinned then the desired PY, PZ, PYJ and PZJ flags are used and the SF26, SF35, SF26J and SF35J values are input at zero. The program will treat these beams as not providing for moments at the appropriate end and direction.

(b) define a beam that can develop a plastic hinge at one or both ends of the beam.

If a plastic hinge is represented the appropriate beam and direction (PY, PZ, PYJ, PZJ) must be flagged and a corresponding (SF35, SF26, SF35J, SF26J) must have a value. The program will treat such a beam as fixed until such time as the plastic moment is formed. *Thereafter the beam moment in the noted direction is maintained* (no longer changes). In order to use the plastic moment equations the user must have beam section properties Z1 or Z2 (card 0501) defined since KRASH computes the plastic moment as follows:

$$M_p = f\left(\frac{\sigma_y I}{y_{max}}\right)$$

where

f = shape factor (SF35, SF26, SF35J, SF26J)

σ_y = material yield stress (contained in the material code table), lb/in^2

I = area moment of inertia, either I_{yy} or I_{zz}, in^4

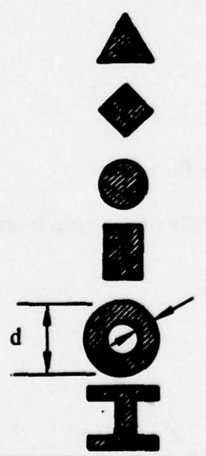
y_{max} = distance to neutral axis either Z1 or Z2, in

The following table shows the relationship between directional moments and appropriate input terms for program KRASH.

TABLE 2-3. RELATIONSHIP FOR DIRECTIONAL MOMENTS AND INPUT TERMS IN KRASH

				APPROPRIATE INPUT REQUIREMENT					
FORCE ALONG AXIS	MOMENT ABOUT AXIS	FORCE, MOMENT DESIGNATION	KRASH DIRECTION NUMBERS	AREA MOMENT OF INERTIAL (CARD 0005)	DISTANCE FROM N.A. TO ELEMENT EXTREME FIBER (CARD 0501)	SHAPE FACTOR "i" END	SHAPE FACTOR "j" END	PIN CODING "i" END	PIN CODING "j" END
z	y	F_z, M_θ	3, 5	I_Y	Z1	SF35	SF35J	PY	PYJ
y	z	F_y, M_ψ	2, 6	I_Z	Z2	SF26	SF26J	PZ	PZJ

TABLE 2-4. SHAPE FACTORS FOR PLASTIC HINGE BEAMS (Reference 14)

SHAPE	SHAPE FACTOR, f (SF35, SF26, SF35J, SF26J IN PROGRAM KRASH
	2.37
	2.0
	1.7
	1.5
	1.40 t/d = 10
	1.27 t = 0
	1.15 Ranges 1.10 to 1.22

$$f = Z/S$$
$$Z = 2\,H_e$$
$$S = I/Y_{max}$$

where:

- I = Section area moment of inertia
- Y_{max} = Distance from neutral axis to extreme fiber
- H_e = Static moment of half the cross section with respect to the neutral axis
- Z = Plastic modulus
- S = Elastic section modulus
- f = Shape factor

CARDS 0801 – 08NUB: **AXIALLY UNSYMETRIC BEAM ELEMENT PARAMETERS**

DESCRIPTION: Defines end points, type of load, and deadband for the beam elements with unsymetrical axial properties in the KRASH model.

FORMAT AND EXAMPLE:

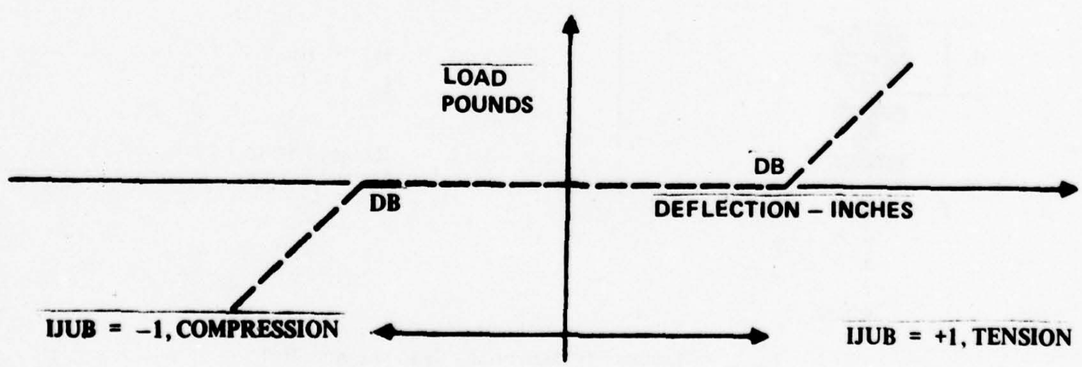
0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J	IJUB		DB						
	2	1	5	–1		1.5						0801

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
IJUB	Flag For The Type Of Axial Loading In The Beam Elements *IJUB = +1, Tension Only* IJUB = -1, Compression Only
DB	Deadband for axial loading, inches

REMARKS:

(1) Optional data card(s).
(2) "NUB" on card 0004 specifies the number of these cards for input.
(3) Blank entries are read as zero.
(4) The general form of the load-deflection curve for the axially unsymetric beam element is as follows:



(5) This type of beam element may also incorporate nonlinear characteristics by specifying the nonlinear properties per the 1200-series cards.
(6) The axial load-deflection curves that can be obtained using this capability are described in Volume I, Section 1.3.5.3.5.
(7) Format for this card is 2 (I2, I3), I5, 5X, E 10.0.
(8) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0900: SHOCK STRUT DATA

DESCRIPTION: Friction force coefficient

FORMAT EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	 34567890
ALPHAP								
1.0								0900

FIELD	CONTENTS
ALPHA	Constant For Use In Computing Shock Strut Friction Force

REMARKS:

(1) Optional data card.
(2) Required only if NOLEO >0 (card 004)
(3) Only 1 card regardless of NOLEO value
(4) Blank entry read as zero
(5) Range of ALPHAP is between .1 to 2.0. The smaller the alphap used the closer the representation is to pure Coulomb friction. Generally a value of 1.0 is suitable.
(6) See Appendix A for the discussion on oleo friction forces for alphap selection.
(7) Format for this card is E10.0.
(8) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 0901 –
09NOLEO: SHOCK STRUT DATA

DESCRIPTION: Air curve parameters

FORMAT EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J		EOLEO	FAO	FAA	EXPOLE	YMAX			
	1		7		10.27	116.	5.	1.0	9.32			0901

FIELD	CONTENTS
M	Massless Node Point Number In End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
EOLEO	Effective Total Strut Cylinder Length, in.
FAO	Fully Extended Gear Preload, lb.
FAA	Ambient Air Preload, lb.
EXPOLE	Polytropic Exponent.
YMAX	Maximum Stroke, in.

REMARKS:

(1) Optional data cards.
(2) "NOLEO" on card 0004 specifies the number of these cards for input.
(3) All entries requiring scientific notation (X.XEXX) should be right justified.
(4) EXPOLE ranges from 1 (isothermal) to 1.4 (adiabatic). Adiabatic condition will usually prevail.
(5) See Appendix A for a description of the shock strut parameters and their usage.
(6) Format for this card is 2 (I2, I3), 5E10.0.
(7) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 1001–
10NOLEO: SHOCK STRUT DATA

DESCRIPTION: Damping constants, linear springs at extended and compressed ends of strut travel and coulomb friction.

FORMAT EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J	BOLEO	BROLEO	XKEXT	XKCOMP	FCOUL			
	1		7	0.24	0.48	10000.	10000.	5.5			1001

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
BOLEO	Strut Orifice Damping lb-sec^2/in^2
BROLEO	Strut Rebound Valve Damping lb-sec^2/in^2
XKEXT	Linear Spring At Extended End Of Strut Travel, lb/in.
XKCOMP	Linear Spring At Compressed End Of Strut Travel, lb/in.
FCOUL	Coulomb Or Constant Friction Force, lbs.

REMARKS:

(1) Optional data cards.
(2) "NOLEO" on card 0004 specifies the number of these cards for input.
(3) All entries requiring scientific notation (X.XEXX) should be right justified.
(4) Format for this card is 2 (I2, I3), 5E10.0.
(5) See Appendix A for a description of the shock strut parameters and their usage.
(6) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARD 1100: BEAM ELEMENT DAMPING RATIO

DESCRIPTION: Defines an overall damping ratio for the beam elements in the KRASH model.

FORMAT AND EXAMPLE:

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

DAMPC							
0.04							1100

FIELD CONTENTS

FIELD	CONTENTS
DAMPC	Damping Ratio (Actual/Critical)

REMARKS:

(1) Required data card; however, it may be blank.
(2) Blank entry is read as zero damping for all beams.
(3) DAMPC values generally range from .02 to .10. Suggest .04 value.
(4) Format for this card is E10.0
(5) Use columns 73-80 to number the input data.

CARDS 1101–
11ND. NON-STANDARD BEAM ELEMENT DAMPING RATIOS

DESCRIPTION: Defines the end points and damping ratio for each beam element in the KRASH model for which a non-standard damping ratio is required.

FORMAT AND EXAMPLE:

0	1			2	3	4	5	6	7		8
12	345	67	890	1234567890	1234567890	1234567890	1234567890	1234567890	12	3	4567890
M	I	N	J	C							
	2	1	5	0.023							1101

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
C	Damping Ratio (Actual/Critical)

REMARKS:

(1) Optional data card(s).
(2) "ND" on card 0004 specifies the number of these cards for input.
(3) Blank entries are read as zero.
(4) Format for this card is 2 (I2, I3), E10.0.
(5) Use columns 73-80 to number the input data.

CARDS 1201 – 12NLB: NONLINEAR BEAM ELEMENT PARAMETERS

DESCRIPTION: Defines the end points, degree-of-freedom, KR table type, and linear deflection points for the nonlinear beam elements in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J	L	NP	LDP	LDP1					
	2	1	5	3	7	1.5	0.0					1201

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
L	Nonlinear Degree-Of-Freedom Where L = 1, 2, 3, 4, 5, 6 Corresponds To The Beam Element Coordinate System Directions X, Y, Z, ϕ, θ, ψ. Respectively (Right Justified Integer)
NP	Number Of Data Points Used In KR Table (Right Justified Integer)
LDP	Deflection At Which Nonlinear Behavior Begins – Inches
LDP1	Deflection At Which Nonlinear Behavior Ends And Linear Restiffening Begins – Inches

REMARKS:

(1) Optional data card(s).
(2) "NLB" on card 0004 specifies the number of these cards for input.
(3) Blank entries are read as zero.
(4) The nonlinear degrees-of-freedom are specified in the beam element coordinate systems shown in Figure 2-3.
(5) For "NP" = 5-9 the corresponding standard KR tables are shown in Figure 2-4. For "NP" >9 the user will input a nonstandard KR table with "NP" data points.
(6) "LDP1" is used only for the KR table "NP" = 9.
(7) The theory on how the KR curves are used to calculate internal beam loads is shown in Volume I, Section 1.3.5.3.4.
(8) Format for this card is 2 (I2, I3) 2I5, 2E10.0.
(9) Use columns 73-80 to number the input data.

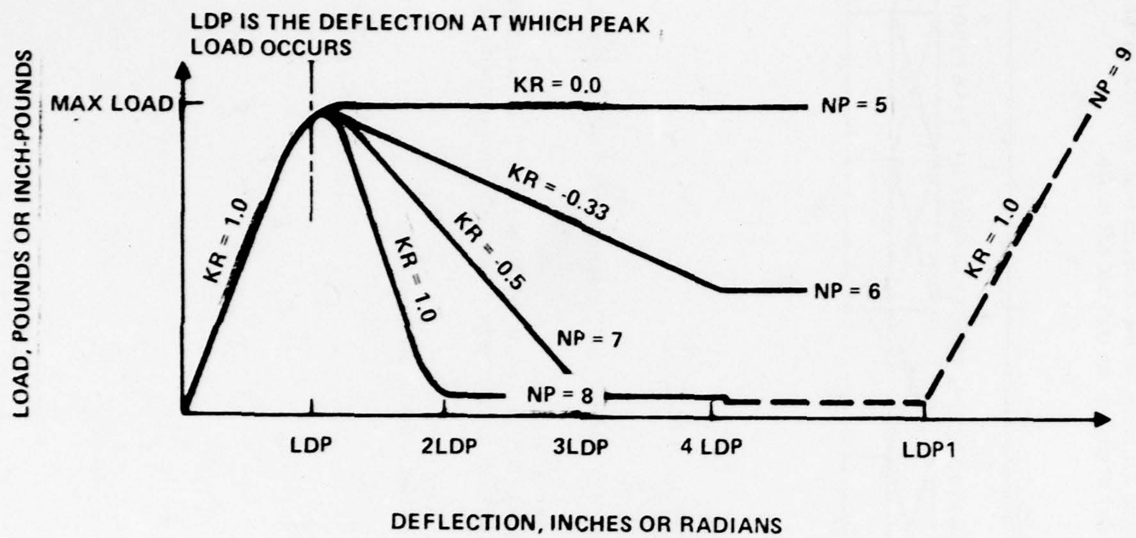


Figure 2-4. Standard Nonlinear Beam Element Stiffness Reduction Curves

CARDS 1301
13XX: NON-STANDARD KR TABLE DATA POINTS

DESCRIPTION: Defines non-standard KR tables for the nonlinear beam elements in the KRASH model which cannot be described with the standard KR tables.

FORMAT AND EXAMPLE:

0 1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
XKR	KR						
1.0	-1.0						1301

FIELD **CONTENTS**

XKR Deflection – Inches
KR Stiffness Reduction Factor at XKR

REMARKS:

(1) Optional data cards.
(2) For each use of "NP" > 9 on the 1200-series cards, "NP" of these cards are required input.
(3) Blank entries are read as zero.
(4) Within each set of "NP" data cards, deflections must be in ascending order.
(5) Each set of "NP" data cards must be ordered to correspond with the 1200 – series cards where "NP" > 9 is used.
(6) Format for this card is 2E10.0.
(7) Use columns 73-80 to number the input data.

CARD 1400: CONTROL VOLUME MASS PENETRATION PARAMETERS

DESCRIPTION: Defines a control volume around a selected mass point in the KRASH model which is monitored for penetration by another mass point during the analysis.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 12	345678	8 90
XN	XP	YN	YP	ZN	ZP				
10.0	10.0	3.0	4.0	10.5	2.9				1400

FIELD	CONTENTS
XN	Distance From Mass Point To Aft Side Of Control Volume
XP	Distance From Mass Point To Forward Side Of Control Volume
YN	Distance From Mass Point To Left Side Of Control Volume
YP	Distance From Mass Point To Right Side Of Control Volume
ZN	Distance From Mass Point To Top Side Of Control Volume
ZP	Distance From Mass Point To Bottom Side Of Control Volume

REMARKS:

(1) Optional data card.
(2) 'MVP" on card 0004 specifies the mass point number for which this data card applies.
(3) Only one mass point may have a control volume.
(4) Blank entries are read as zero.
(5) All distances are positive and units are inches.
(6) For a RUNMOD = 2 the MVP mass should be selected from a mass point located on the airplane centerline. This restriction doesn't apply to RUNMOD = 0 or 1.
(7) Any of the model mass points may penetrate the designated control volume of the model.
(8) The mass penetration calculations are described in Volume I, Section 1.3.10.
(9) Format for this card is 6E10.0.
(10) Use columns 73-80 to number the input data.

CARDS 1401–
140XX: DRI ELEMENT SPECIFICATION

DESCRIPTION: Defines the end mass points of the DRI beam elements in the KRASH model.

FORMAT AND EXAMPLE:

12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	12345	67890	1	234567890
I1	J1	I2	J2	I3	J3	I4	J4	I5	J5	I6	J6	I7	J7	X	
3	10														1401

FIELD	CONTENTS
I1	Mass Point Number At End "I"
J1	Mass Point Number At End "J"

REMARKS:

(1) Optional data card(s).
(2) "NDRI" on card 0004 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) Blank entries are read as zero.
(5) Up to seven DRI beam elements can be specified on each card. (Normally an analysis requires from 1 to 4 DRI elements).
(6) DRI beam element section properties can be defined on the 0500-series cards or if a MTL code of 10 is used the program will automatically compute the DRI properties.
(7) Beams that connect massless node points cannot be used as DRI elements, only direct mass to mass connection is allowed.
(8) The usage of DRI elements is described in Volume I, Section 1.3.12.
(9) Format for this card is 14I5.
(10) Use columns 73-80 to number the input data.

CARDS 1501 – 15NVCH: OCCUPIABLE VOLUME CHANGE PARAMETERS

DESCRIPTION: Defines occupiable volumes in the KRASH model for volume change calculations by specifying the eight corner mass points.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8
I1	I2	I3	I4	I5	I6	I7	I8	
3	7	12	13	21	23	31	35	1501

FIELD / **CONTENTS**

FIELD	CONTENTS
I1	Mass Point Number At Forward End, Upper Left-Hand Corner
I2	Mass Point Number At Forward End, Upper Right-Hand Corner
I3	Mass Point Number At Aft End, Upper Left-Hand Corner
I4	Mass Point Number At Aft End, Upper Right-Hand Corner
I5	Mass Point Number At Forward End, Lower Left-Hand Corner
I6	Mass Point Number At Forward End, Lower Right-Hand Corner
I7	Mass Point Number At Aft End, Lower Left-Hand Corner
I8	Mass Point Number At Aft End, Lower Right-Hand Corner

REMARKS:

(1) Optional data card(s).
(2) "NVCH" on card 0004 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) Blank entries are not allowed.
(5) The volume change calculations are explained in Volume I, Section 1.3.11 (Figure 1-16).
(6) For a symmetrical full model (RUNMOD = 2 type) when only half the data is input the user inputs mass point locations 1, 3, 5, 7 (I1, I3, I5, I7). The opposite side mass point locations 2, 4, 6, 8 (I2, I4, I6, I8) are input as zero (blank). KRASH automatically computes the opposite side masses. See Volume I, Figure 1-16 for mass point designations.
(7) Format for this card is 8I5.
(8) Use columns 73-80 to number the input data.

CARDS 1601–16NVBM: NON-STANDARD MAXIMUM BEAM ELEMENT POSITIVE DEFLECTIONS FOR RUPTURE

DESCRIPTION: Defines the end points and the maximum positive deflections and rotations for rupture of beam elements in the KRASH model.

FORMAT AND EXAMPLE:

M	I	N	J	VMAX1	VMAX2	VMAX3	VMAX4	VMAX5	VMAX6	X	
	2	1	6	10.0	15.2	100.0	100.0	0.2			1601

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
VMAX1	Maximum Deflection In Beam Element X-Direction – Inches
VMAX2	Maximum Deflection In Beam Element Y-Direction – Inches
VMAX3	Maximum Deflection In Beam Element Z-Direction – Inches
VMAX4	Maximum Rotation About Beam Element X-Axis – Radians
VMAX5	Maximum Rotation About Beam Element Y-Axis – Radians
VMAX6	Maximum Rotation About Beam Element Z-Axis – Radians

REMARKS:

(1) Optional data card(s).
(2) "NVBM" on card 0005 specifies the number of these cards for input.
(3) The standard or default values for maximum deflections and rotations are 100 inches and 100 radians, respectively.
(4) The beam element coordinate systems are shown in Figure 2-3.
(5) All values are input as positive numbers.
(6) Format for this card is 2 (I2, I3), 6E10.0.

KRASH INPUT DATA

CARDS 1701–
17NVBMN: NON-STANDARD MAXIMUM BEAM ELEMENT NEGATIVE DEFLECTIONS FOR RUPTURE

DESCRIPTION: Defines The end points and the maximum negative deflections and rotations for rupture of beam elements in the KRASH model

FORMAT AND EXAMPLE:

0 12345	1 67890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
M I	N J	VMAXN1	VMAXN2	VMAXN3	VMAXN4	VMAXN5	VMAXN6	
2	1 6	10.0	15.2	100.0	100.0	0.2	100.0	1701

FIELD	CONTENTS
M	Massless Node Point Number At End "I" (Right Justified Integer)
I	Mass Point Number At End "I" (Right Justified Integer)
N	Massless Node Point Number At End "J" (Right Justified Integer)
J	Mass Point Number At End "J" (Right Justified Integer)
VMAXN1	Maximum Deflection In Beam Element X-Direction – Inches
VMAXN2	Maximum Deflection In Beam Element Y-Direction – Inches
VMAXN3	Maximum Deflection In Beam Element Z-Direction – Inches
VMAXN4	Maximum Rotation About Beam Element X-Axis – Radians
VMAXN5	Maximum Rotation About Beam Element Y-Axis – Radians
VMAXN6	Maximum Rotation About Beam Element Z-Axis – Radians

REMARKS:
(1) Optional data card(s).
(2) "NVBMN" on card 0005 specifies the number of these cards for input.
(3) The standard or default values for maximum deflections and rotations are 100 inches and 100 radians, respectively.
(4) The beam element coordinate systems are shown in Figure 2-3.
(5) All values are input as positive numbers.
(6) Format for this card is 2 (I2, I3), 6E10.0.
(7) Use columns 73-80 to number the input data.

61

CARDS 1801-18NFBM: NONSTANDARD MAXIMUM BEAM ELEMENT POSITIVE LOADS FOR RUPTURE

DESCRIPTION: Defines the end points and the maximum forces and moments for rupture of beam elements in the KRASH model.

FORMAT AND EXAMPLE:

M	I	N	J	FMAX1	FMAX2	FMAX3	FMAX4	FMAX5	FMAX6	X	
	3		7	10.0E10	1000.0	10.0E10	10.0E10	10.0E6	10.0E10		1801

FIELD | CONTENTS

FIELD	CONTENTS
M	Massless Node Point Number at End "I" (Right Justified Integer)
I	Mass Point Number at End "I" (Right Justified Integer)
N	Massless Node Point Number at End "J" (Right Justified Integer)
J	Mass point Number at End "J" (Right Justified Integer)
FMAX1	Maximum Axial Force in Beam Element X-Direction - Pounds
FMAX2	Maximum Shear Force in Beam Element Y-Direction - pounds
FMAX3	Maximum Shear Force in Beam Element Z-Direction - Pounds
FMAX4	Maximum Torque About Beam Element X-Axis - Inch * Pounds
FMAX5	Maximum Bending Moment About Beam Element Y-Axis - Inch * Pounds
FMAX 6	Maximum Bending Moment About Beam Element Z-Axis - Inch * Pounds

REMARKS:

(1) Optional data card(s).
(2) "NFBM" on card 0005 specifies the number of these cards for input.
(3) The standard of default values for maximum rupture forces and moments are 10.0E10 pounds and 10.0E10 inch-pounds, respectively.
(4) Entries requiring scientific notation (X.XEXX) should be right justified.
(5) Blank entries are read as zero.
(6) The beam element coordinate systems are shown in Figure 2-3.
(7) All values are input as positive numbers.
(8) Format for this card is 2(I2,I3), 6E10,0.
(9) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 1901-19NFBMN: NON-STANDARD MAXIMUM BEAM ELEMENT NEGATIVE LOADS FOR RUPTURE

DESCRIPTION: Defines the end points and the maximum forces and moments for rupture of beam elements in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J	FMAXN1	FMAXN2	FMAXN3	FMAXN4	FMAXN5	FMAXN6	X	
	3		7	10.0E10	1000.0	10.0E10	10.0E10	10.0E6	10.0E10		1901

FIELD	CONTENTS
M	Massless Node Point Number at End 'I' (Right Justified Integer)
I	Mass Point Number at End 'I' (Right Justified Integer)
N	Massless Node Point Number at End 'J' (Right Justified Integer)
J	Mass Point Number at End 'J' (Right Justified Integer)
FMAXN1	Maximum Axial Force In Beam Element X-Direction – Pounds
FMAXN2	Maximum Shear Force In Beam Element Y-Direction – Pounds
FMAXN3	Maximum Shear Force In Beam Element Z-Direction – Pounds
FMAXN4	Maximum Torque About Beam Element X-Axis – Inch * Pounds
FMAXN5	Maximum Bending Moment About Beam Element Y-Axis – Inch * Pounds
FMAXN6	Maximum Bending Moment About Beam Element Z-Axis – Inch * Pounds

REMARKS:

(1) Optional data card(s).
(2) 'NFBMN' on card 0005 specifies the number of these cards for input.
(3) The standard or default values for maximum rupture forces and moments are 10.0E10 pounds and 10.0E10 inch-pounds, respectively.
(4) Entries requiring scientific notation (X.XEXX) should be right justified.
(5) Blank entries are read as zero.
(6) The beam element coordinate systems are shown in Figure 2-3.
(7) All values are input as positive numbers.
(8) Format for this card is 2(I2, I3), 6E10.0.
(9) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 2001-20NHI: **MISCELLANEOUS MASS POINT PARAMETERS**

DESCRIPTION: Defines any nonzero aerodynamic lift forces, angular moments of rotating masses, and mass cross products of inertia for mass points in the KRASH model.

FORMAT AND EXAMPLE:

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

I	LC	HEX	HEY	HEZ	XYI	YZI	XZI	X	
7	0.0	100.0	0.0	0.0	1.3	-3.3	0.0		2001

FIELD	CONTENTS
I	Mass Point Number (Right Justified Integer)
LC	Lift Coefficient For Aerodynamic Force, Positive Up
HEX	Angular Momentum of Rotating Masses About Mass Point X-Axis – Inch * Pound * Second
HEY	Angular Momentum of Rotating Masses About Mass Point Y-Axis – Inch * Pound * Second
HEZ	Angular Momentum of Rotating Masses About Mass Point Z-Axis – Inch * Pound * Second
XYI	Mass Cross Product of Inertia in Mass Point X-Y Plane – Inch * Pound * Second **2
YZI	Mass Cross Product of Inertia in Mass Point Y-Z Plane – Inch * Pound * Second **2
XZI	Mass Cross Product of Inertia in Mass Point X-Y Plane – Inch * Pound * Second **2

REMARKS:

(1) Optional data card(s).
(2) 'NHI' on card 0005 specifies the number of these cards for input.
(3) Blank entries are read as zero.
(4) The airplane weight is multiplied by the lift coefficient to generate an aerodynamic lift force on the mass point.
(5) Format for this card is I5,F5.0, 6E10.0.
(6) Use columns 73-80 to number the input data.

CARD 2101 - 21 NPH: MASS POINT EULER ANGLES

DESCRIPTION: Defines for any mass point in the KRASH model three Euler angles to arbitrarily rotate the mass point or body coordinate system relative to the airplane coordinate system.

FORMAT AND EXAMPLE:

0 12345	1 67890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	 12	8 34567890
I		PHIDP	THEDP	PSIDP					
3		0.157	0.0	0.0					2101

FIELD	CONTENTS
I	Mass Point Number (Right Justified Integer)
PHIDP	Roll Euler Angle about Airplane X-Axis - Radians
THEDP	Pitch Euler Angle about Airplane Y-Axis - Radians
PSIDP	Yaw Euler Angle about Airplane Z-Axis - Radians

REMARKS:

(1) Optional data card(s).
(2) "NPH" on card 0005 specifies the number of these cards for input.
(3) Euler angles are order-dependent rotations.
(4) Blank entries are read as zero.
(5) These angles relate the mass-fixed axes to the airplane axes. Normally these axes coincide and therefore the angles are zero. If mass inertia were available in an inclined axis system the user might want to utilize this option. It is suggested that for this situation the user hand calculate the inertias in the desired axes. A more likely reason for inclining mass axes away from the airplane axes is to enable the user to orient an external spring in a direction that doesn't coincide with any of the airplane axes (external springs must point along one of the mass fixed axes).
(6) Roll angle positive when mass axes are "right-wing-down" relative to cg axes. Pitch angle positive when mass axes are "nose-up" relative to cg axes. Yaw angle positive when mass axes are "nose-right" relative to cg axes.
(7) Format for this card I5, 5X, 3E10, 0.
(8) Use columns 73-80 to number the input data.

CARDS 2201 - 22NACC: MASS POINT TIME HISTORY ACCELERATION PARAMETERS

DESCRIPTION: Defines the mass point number, degree-of-freedom, and number of data points to specify an acceleration time history for any mass point in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

I	L	NP							
3	2	10							2201

FIELD	CONTENTS
I	Mass Point Number.
L	Degree-of-Freedom where L = 1, 2, 3, 4, 5, 6 corresponds to X, Y, Z, θX, θY, θZ in the Mass Point or Body Coordinate System
NP	Number of Data Points in the Table that specifies the Acceleration Time History

REMARKS:
(1) Optional data card(s).
(2) "NACC" on card 0004 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) All entries must be nonzero.
(5) Each use of this card requires that "NP" number of the 2300-series cards be used.
(6) The masses must be input in sequence starting with the lower numbered masses.
(7) Format for this card is 3I5.
(8) Use columns 73-80 to number the input data.

CARDS 2301-23XX: **MASS POINT ACCELERATION TIME HISTORY DATA TABLE**

DESCRIPTION: Defines a table of time and acceleration data points for each mass point specified on the 2200-series cards.

FORMAT AND EXAMPLE:

0 1	2	3	4	5	6	7		8
1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	1	234567890
T	ACCEL							
0.01	386.0							2301

FIELD	CONTENTS
T	Time - Seconds
Accel	Acceleration - Inches per Second **2 or Radians per Second **2

REMARKS:

(1) Optional data cards.
(2) For each of the "NACC" number of 2200-series cards, "NP" number of these cards are required.
(3) Within each set of data, the "NP" cards must be arranged in ascending order of time.
(4) Each set of data must be ordered to correspond with the 2200 series cards.
(5) Blank entries are read as zero.
(6) A maximum of 300 acceleration times are allowed. For example, if accelerations are applied to 50 masses, the time history of each location can not exceed a curve consisting of 6 points.
(7) The values of acceleration are the time derivative of the mass axis velocities $\dot{u}$, $\dot{v}$, $\dot{w}$ (See Equation 1-117 Volume I).
(8) Format for this card is 2E10.0.

CARDS 2400-24XX: DIRECT INPUT OF BEAM ELEMENT 6X6 STIFFNESS MATRIX

DESCRIPTION: Defines the end points and 6x6 stiffness matrix terms for any beam element in the KRASH model.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	N	J								
	2	1	7								2400

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K11	K12	K13	K14	K15	K16			
3500.0	0.0	0.0	0.0	0.0	0.0			2401

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K21	K22	K23	K24	K25	K26			
0.0	1.7E07	0.0	0.0	0.0	−2.2E05			2402

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K31	K32	K33	K34	K35	K36			
0.0	0.0	1.7E07	0.0	0.3E05	0.0			2403

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K41	K42	K43	K44	K45	K46			
0.0	0.0	0.0	15200.0	0.0	0.0			2404

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K51	K52	K53	K54	K55	K56			
0.0	0.0	0.3E06	0.0	3.5E09	0.0			2405

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

K61	K62	K63	K64	K65	K66			
0.0	−2.2E05	0.0	0.0	0.0	3.5E09			2406

KRASH INPUT DATA

CARDS 2400-24XX: DIRECT INPUT OF BEAM ELEMENT 6X6 STIFFNESS MATRIX (Continued)

FIELD	CONTENTS
M	Massless Node Point Number at end "I" (Right Justified Integer)
I	Mass Point Number at end "I" (Right Justified Integer)
N	Massless Node Point Number at end "J" (Right Justified Integer)
J	Mass Point Number at end "J" (Right Justified Integer)
KIJ	Stiffness Matrix Terms - Pounds per Inch or Inch * Pounds per Radian

REMARKS:

(1) Optional data cards.
(2) "NKM" on card 0005 specifies the number of these card sets for input.
(3) Blank entries are read as zero.
(4) The beam element must be included on the 0500-series cards.
(5) The stiffness data on these cards will override any values calculated with the beam element section properties on the 0500-series cards.
(6) The input 6x6 stiffness matrix (shown below) corresponds to the lower right-hand quadrant of a full 12x12 beam element stiffness matrix.
(7) Entries requiring scientific notation (X.XEXX) should be right justified.
(8) Format for card 2400 type is 2(I2, I3).
(9) Format for card 2401-2406 types is 6E10.0 stiffness matrix.
(10) Use columns 75-80 to number the input data.

CARDS 2501-25NPLT: MASS POINT POSITION (STRUCTURE DEFORMATION) PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the planar view, scale factors, and mass point numbers for each mass point position (structure deformation) printer plot.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

NTPL	NMPTS	ISCALE		XSCALE	YSCALE					
1	10	3		10.0	10.0					2501

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14		
1	2	5	6	7	11	13	14	21	27						2502

FIELD	CONTENTS
NTPL	Flag to select Planar View where NTPL = 1, 2, 3 corresponds to top, side, and frontal views, respectively (Right Justified Integer)
NMPTS	Number of Mass Points (Right Justified Integer - Maximum allowed is 50)
ISCALE	Flag to Select Scaling Option as follows (Right Justified Integer):

ISCALE	TYPE OF SCALING
0	Automatic scaling where horizontal and vertical plot axes scales are selected independently based on the corresponding largest mass point displacement components.
1	Automatic scaling where horizontal and vertical plot axes scales are set equal based on largest mass point displacement component.
3	User defined scaling

XSCALE	Horizontal Scale Factor required if "ISCALE" = 3
YSCALE	Vertical Scale Factor required if "ISCALE" = 3
MI	Mass Point Number (Right Justified Integer)

REMARKS:

(1) Optional data cards.
(2) "NPLT" on card 0011 specifies the number of these card sets for input.
(3) "NTPL," "NMPTS," and "MI" must be nonzero.
(4) Blank entries are read as zero.
(5) Scale factor units are inches of mass point displacement per inch of paper.
(6) Entries requiring scientific notation (X.XEXX) should be right justified.
(7) Recommend ISCALE = 3 if user plans to compare or overlay plots at different time periods.
(8) Format for card 2501 type is 3I5,5X,2E10.0.
(9) Format for card 2502 type is 14I5.
(10) Use columns 73-80 to number the input data.

CARDS 2601-21NMEP: MASS POINT PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the mass point number and flags to specify which mass point output quantity time histories will be printer plotted.

FORMAT AND EXAMPLE:

```
0         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

I	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8					
3	0	1	0	1	0	0	1	0					2601

FIELD	CONTENTS
I	Mass Point Number
MP1	Flag for Linear Displacements (X, Y, Z - Inches) in the Ground Coordinate System
MP2	Flag for Euler Angles (PHI, THETA, PSI - Radians) in the Airplane Coordinate System
MP3	Flag for Linear Velocities (X, Y, Z - Inches per Second) in the Ground Coordinate System
MP4	Flag for Linear Velocities (U, V, W - Inches per Second) in the Mass Point or Body Coordinate System
MP5	Flag for Angular Velocities (P, Q, R - Radians per Second) in the Mass Point or Body Coordinate System
MP6	Flag for Unfiltered Linear Accelerations (X, Y, Z - G's) in the Mass Point or Body Coordinate System
MP7	Flag for Filtered Linear Accelerations (X, Y, Z - G's) in the Mass Point or Body Coordinate System
MP8	Flag for Angular Accelerations (P, Q, R - Radians per Second**2) in the Mass Point or Body Coordinate System
MP9	Flag for Impulse (X, Y, Z in G-sec., P, Q, R in (RAD Per Sec) in Mass Point or Body Coordinate Axes for Filtered Data

REMARKS:

(1) Optional data card(s).
(2) "NMEP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "I" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) Format for this card is 10I5.
(8) Use columns 73-80 to number the input data.

CARDS 2701-27NNEP: MASSLESS NODE POINT PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the massless node point number, mass point number, and flags to specify which massless node point output quantity time histories will be printer plotted.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

M	I	NP1	NP2	NP3	NP4	NP5	NP6					
1	7	0	1	0	1	0	0					2701

FIELD	CONTENTS
M	Massless Node Point Number
I	Mass Point Number
NP1	Flag for Linear Displacements (X, Y, Z - Inches) in the Ground Coordinate System
NP2	Flag for Linear Velocities (X, Y, Z - Inches per Second) in the Ground Coordinate System
NP3	Flag for Linear Velocities (U, V, W - Inches per Second) in the Mass Point or Body Coordinate System
NP4	Flag for Unfiltered Linear Accelerations (X, Y, Z - G's) in the Mass Point or Body Coordinate System
NP5	Flag for Filtered Linear Accelerations (X, Y, Z - G's) in the Mass Point or Body Coordinate System
NP6	Flag for Impulse (X, Y, Z in G-sec. P, Q, R in RAD/Sec) in Mass Point or Body Coordinate System

REMARKS:

(1) Optional data card(s).
(2) "NNEP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "M" and "I" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) Format for this card is 8I5.
(8) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 2801-28NBFP: BEAM ELEMENT LOADS PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the beam element number and flags to specify which beam element internal load time histories will be printer plotted.

FORMAT AND EXAMPLE:

0 12345	1 67890	 12345	2 67890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	7 12	8 34567890
IJ	BFP1	BFP2	BFP3	X	X	X	X	X	X	
27	0	1	0							2801

FIELD	CONTENTS
IJ	Beam Element Number
BFP1	Flag for Axial and Shear Forces (FX, FY, FZ - Pounds)
BFP2	Flag for Torque and Bending Moments at End "I" (MX, MY, MZ - Inch * Pounds)
BFP3	Flag for Torque and Bending Moments at End "J" (MX, MY, MZ - Inch * Pounds)

REMARKS:

(1) Optional data card(s).
(2) "NBFP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "IJ" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) All internal load data is output in the beam element coordinate systems shown in Figure 2-3.
(8) Format for this card is 4I5.
(9) Use columns 73-80 to number the input data.

CARDS 2901-29NBDP: BEAM ELEMENT DEFLECTION-ROTATION PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the beam element number and flags to specify which beam element deflection and rotation time histories will be printer plotted.

FORMAT AND EXAMPLE:

0 12345	1 67890	12345	2 67890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
TJ	BDP1	BDP2	BDP3						
3	0	0	1						2901

FIELD CONTENTS

FIELD	CONTENTS
IJ	Beam Element Number
BDP1	Flag for Deflection Differences of End "J" and End "1" (X, Y, Z - Inches)
BDP2	Flag for Rotation Differences of End "J" and End "1" (Phi, Theta, Psi - Radians)
BDP3	Flag for Rotation Sums of End "J" and End "1" (Phi, Theta, Psi - Radians)

REMARKS:
(1) Optional data card(s).
(2) "NBDP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "IJ" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) All deflection-rotation data is output in the beam element coordinate systems shown in Figure 2-3.
(8) Format for this card is 4I5.
(9) Use columns 73-80 to number the input data.

KRASH INPUT DATA

CARDS 3001-30NSTP: BEAM ELEMENT STRESS RATIO PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the beam element number and flags to specify which beam element stress ratio time histories will be printer plotted.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8
IJ	STP1	STP2	STP3	STP4	STP5			
7	0	1	1	0	0			3001

FIELD	CONTENTS
IJ	Beam Element Number
STP1	Flag for Stress Ratio for Top and Bottom Fibers Using Maximum Shear Stress Theory
STP2	Flag for Stress Ratio of Left and Right Fibers Using Maximum Shear Stress Theory
STP3	Flag for Stress Ratio of Top and Bottom Fibers using Constant Energy of Distortion Theory
STP4	Flag for Stress Ratio of Left and Right Fibers Using Constant Energy of Distortion Theory
STP5	Flag for Stress Ratio of Tension-Only, Compression-Only, and Axial Buckling Loads

REMARKS:

(1) Optional data card(s).
(2) "NSTP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "IJ" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) Stress parameters must be provided for the beam elements on the 0500-series cards.
(8) "NSC" on card 0005 must be flagged "yes."
(9) Format for this card is 6I5.
(10) Use columns 73-80 to number the input data.

CARDS 3101-31NSEP: EXTERNAL CRUSHING SPRING LOAD-DEFLECTION PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the end point and flags to specify which external crushing spring load and deflection time histories will be printer plotted.

FORMAT AND EXAMPLE:

0 1234567890	1 1234567890	2 1234567890	3 1234567890	4 1234567890	5 1234567890	6 1234567890	7 1234567890	8 1234567890
I	M	SEP1	SEP2					
3	1	1	0					3101

FIELD	CONTENTS
I	Mass Point Number
M	Massless Node Point Number
SEP1	Flag for Axial Deflection (Inches)
SEP2	Flag for Axial Loads (Pounds)

REMARKS:
(1) Optional data card(s).
(2) "NSEP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "I" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) All external crushing springs attached to the same mass point/massless node point will be printer plotted if that end point is specified.
(8) Format for this card is 4I5.
(9) Use columns 73-80 to number the input data.

CARDS 3201-32NENP: BEAM ELEMENT STRAIN AND DAMPING ENERGY PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the beam element number and flags to specify which beam internal element load time history will be printer plotted

FORMAT AND EXAMPLE:

0 12345	1 67890 12345	2 67890 12345	3 67890 12345	4 67890 12345	5 67890 12345	6 67890 12345	7 67890 12345	8 67890
IJ	ENG1	ENG2						
2	1	1						3201

FIELD	CONTENTS
IJ	Beam Element Number
ENG1	Flag for Strain Energy (in.-lb.)
ENG2	Flag for Damping Energy (in.-lb.)

REMARKS:

(1) Optional data cards.
(2) "NENP" on card 0011 specifies the number of these cards for input.
(3) All entries must be right justified.
(4) "IJ" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) Format for this card is 3I5.
(8) Use column 73-80 to number the input data.

CARDS 3301-33NDRP: DYNAMIC RESPONSE INDEX (DRI) PRINTER PLOT PARAMETERS

DESCRIPTION: Defines the mass point number of a DRI beam element for dynamic response index (DRI) time history printer plots.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

J									
27									3301

FIELD CONTENTS

J Mass Point Number

REMARKS:
(1) Optional data card(s).
(2) "NDRP" on card 0011 specifies the number of these cards for input.
(3) All entries are right justified integers.
(4) "J" must be nonzero.
(5) Blank entries are read as zero.
(6) Flags for printer plot time histories are defined as follows:
0 = No
1 = Yes
(7) The mass point number must be end "J" of a DRI beam element.
(8) Format for this card is I5.
(9) Use columns 73-80 to number the input data.

CARD 3400: END OF DATA

DESCRIPTION: Defines the final card of the input data.

FORMAT AND EXAMPLE:

0 1 2 3 4 5 6 7 8
12345678901234567890123456789012345678901234567890123456789012345678901234567890

END	
END	3400

FIELD CONTENTS

End The Mnemonic "End" (Left Justified)

REMARKS:
(1) Required data card.
(2) Use columns 73-80 to number the input data.

2.2 OUTPUT AND SAMPLE CASE

The print output consists of six major sections. These are:

- Direct listing of input data cards, termed "echo" of the input data
- Formatted print out of the input data with descriptive titles
- Model parameter data, internally calculated from input data
- Time history of model response parameters
- Summary of time variations of energy terms, and time of occurrence of mass penetrations, beam yielding and ruptures, external spring loading and formation of plastic hinges.
- Time history plots of selected response quantities

Each of the above sections of print output is discussed in the following subsections, and illustrated with the output from a representative sample math case. The 16 mass 32 beam math model is shown in Figure 2-5. Included in the model are provisions for the following:

NSP = 10	external springs
NLB = 2	nonlinear beams
NNP = 6	massless mode points
NPIN = 5	pin-ended beams
NUB = 4	unsymmetrical beams
NDRI = 1	DRI's
ND = 1	beam damping inputs
RUNMOD = 2	

The sample case data is presented to illustrate input-output format and is not necessarily representative of an actual vehicle or crash condition.

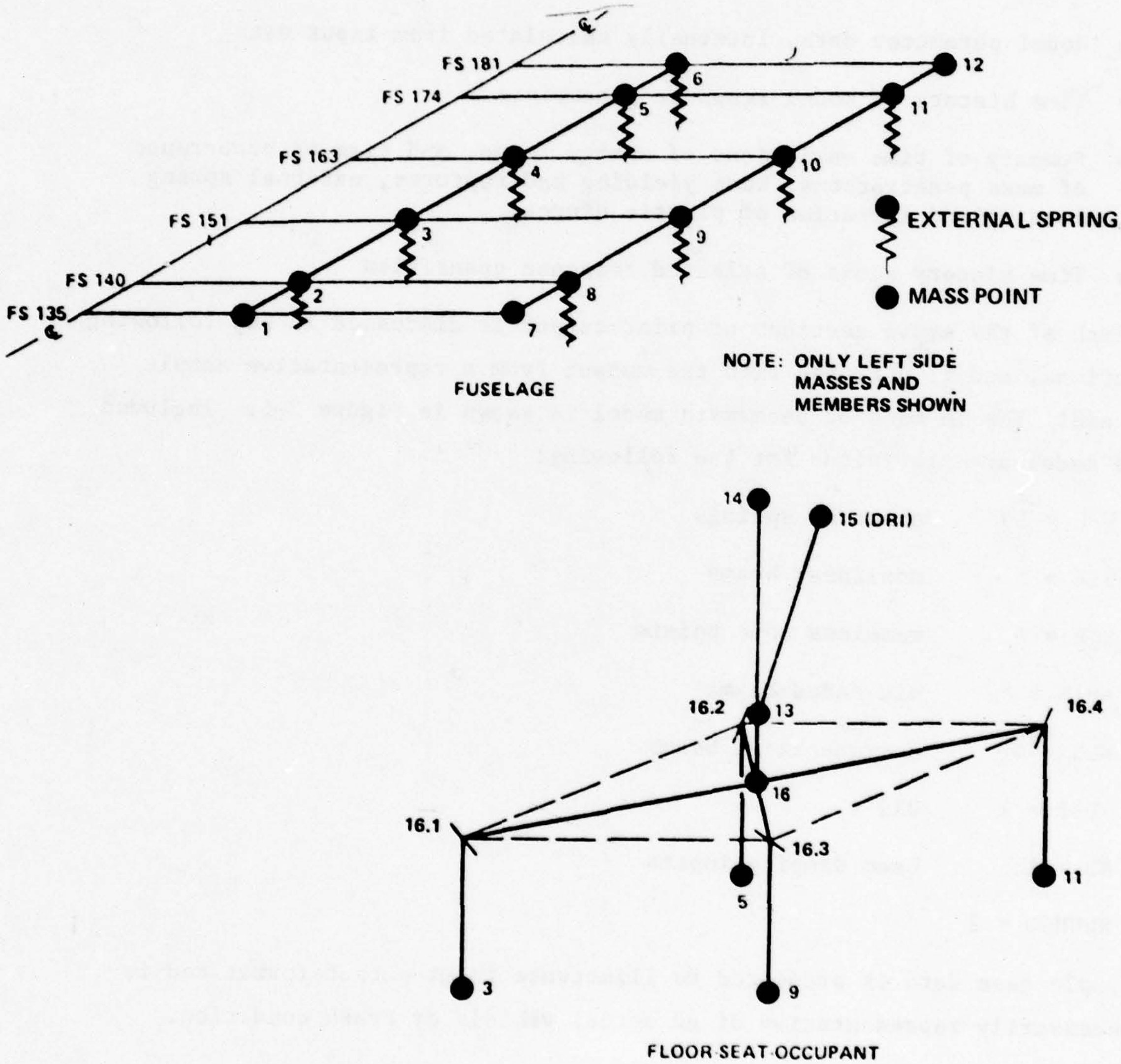


Figure 2-5. 16 Mass, 32 Member Sample Math Model

2.2.1 Echo of Input Data

This is a direct listing of the input data cards for the case being analyzed. Figure 2-6 illustrates this print for the sample case. The card listing is preceded by a heading which identifies the column number for the following cards. The sequence number is in columns 77-80. The numbers in these columns normally correspond to the card sequence numbering scheme shown in Figure 2-1, the input data format. In this particular case, an overall sequential numbering scheme is used for compatibility with a remote terminal editing system. This print-out is useful for scanning and editing the input data set, in addition to providing an exact literal copy of all the input data for each case. This output is provided twice; one can be used to mark up a data set to form a new case, and the other can remain as a clean record of the input for that case.

2.2.2 Formatted Print-Out of Input Data

This section of the print output organizes all the input data into logical groups and prints out the data with self-explanatory identification headings. This output is illustrated in Figure 2-7 for the sample case. The data is organized in the following major groups:

- Case title cards
- Program size data
- Program data management control data (restart option)
- Program control data
- Vehicle initial conditions
- Generalized surface data
- Corresponding mass and beam numbering (RUNMOD = 2)
- Mass data
- Node point data (optional)
- External spring data

ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

```
                   1         2         3         4         5         6         7         8
CARD NO.  12345678901234567890123456789012345678901234567890123456789012345678901234567890

     1    SAMPLE CASE SUBSECTIN DROP TEST SIMULATION  16MASS/32MEMBER MODEL       00000010
     2    6-1-79 KRASH.F79.DATA 27.5 FT./SEC                                      00000020
     3    12345678901234567890123456789012345678901234567890123456789012345678901200000030
     4       16   10   32    2    6    5    4    1    0    0    0    0    0    1 00000040
     5        0    0    0    0    0    0    0   10   50  100    1    1           00000050
     6                                                                            00000060
     7                                                                            00000070
     8              100 0.00001   0.002     0.0        85.0       2.0             00000080
     9                                                                            00000090
    10        1    1    1    1    1    1    1    1                                00000100
    11        5    1    2    2    1    4    2    1    2   20                      00000110
    12     0.0       0.0       330.0                                              00000120
    13     0.0       0.0       0.0                                                00000130
    14     0.0       0.0131    0.0       0.0       0.0       0.0                  00000140
    15     1.570     135.0     6.0       -16.0     0.13500   0.02380   0.05100    00000150
    16     5.030     140.0     6.0       -16.0     0.43400   0.17420   0.27540    00000160
    17     17.21     151.0     6.0       -16.0     4.30      4.40      0.54600    00000170
    18     7.21      163.0     6.0       -16.0     0.62      0.30      0.441      00000180
    19     5.64      174.0     6.0       -16.0     0.486     0.199     0.29600    00000190
    20     2.2       181.0     6.0       -16.0     0.18930   0.05350   0.09140    00000200
    21     3.13      135.0     20.0      -16.0     1.816     1.700     0.1827     00000210
    22     10.029    140.0     20.0      -16.0      5.813     5.75     0.893      00000220
    23     24.42     151.0     20.0      -16.0     12.15     12.20     1.60       00000230
    24     14.42     163.0     20.0      -16.0      8.355     8.46     1.479      00000240
    25     11.2823   174.0     20.0      -16.0      6.538     7.17     1.136      00000250
    26     4.39      181.0     20.0      -16.0     2.540      2.3800   0.2560     00000260
    27     72.86     166.0     13.0       5.8      13.9511   14.7742   16.8341    00000270
    28     72.86     166.0     13.0       20.89    11.3116   10.7989   6.5318     00000280
    29     72.86     166.0     13.0       20.89    11.3116   10.7989   6.5318     00000290
    30     20.5      166.0     13.0      -1.7      5.95      6.6062    3.152      00000300
    31        1   13 166.0     13.0       5.8                                     00000310
    32        1   16 151.0     6.0        -1.7                                    00000320
    33        2   16 174.0     6.0        -1.7                                    00000330
    34        3   16 151.0     20.0       -1.7                                    00000340
    35        4   16 174.0     20.0       -1.7                                    00000350
    36        5   16 166.0     13.0      -1.7                                     00000360
    37        2    3 8.0       0.0       10000.0                                  00000370
    38        3    3 8.0       0.0       10000.0                                  00000380
    39        4    3 8.0       0.0       10000.0                                  00000390
    40        5    3 8.0       0.0       10000.0                                  00000400
    41        6    3 8.0       0.0       10000.0                                  00000410
    42        8    3 3.3       0.0       10000.0                                  00000420
    43        9    3 3.3       0.0       10000.0                                  00000430
    44       10    3 3.3       0.0       10000.0                                  00000440
    45       11    3 3.3       0.0       10000.0                                  00000450
    46       12    3 3.3       0.0       10000.0                                  00000460
    47     0.100     0.500     0.750     4.0       2290.0    2290.     .00        00000470
    48     0.100     0.500      .750     4.0       2650.0    2650.     .00        00000480
    49     0.100     0.500     0.750     4.0       2650.0    2650.     .00        00000490
    50     0.100     0.500     0.750     4.0       2410.0    2410.     .00        00000500
```

Figure 2-6. Echo of the Input Data (Sheet 1 of 3)

ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

```
                   1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

      51  0.100     0.500     0.750     4.0       1760.0    1760.    .00           00000510
      52  0.250     0.500     0.750     4.000     670.0     1380.    .00           00000520
      53  0.250     0.500     0.750     4.000     670.0     1380.    .00           00000530
      54  0.250     0.500     0.750     4.000     670.0     1380.    .00           00000540
      55  0.250     0.500     0.750     4.000     670.0     1380.    .00           00000550
      56  0.250     0.500     0.750     4.000     670.0     1380.    .00           00000560
      57     1    2 0.615674            4.18228   0.060521            5.78 .667 400000570
      58     2    3 0.615674            4.18228   0.060521            5.78 .667 400000580
      59     3    4 0.615674            4.18228   0.060521            5.78 .667 400000590
      60     4    5 0.615674            4.18228   0.060521            5.78 .667 400000600
      61     5    6 0.615674            4.18228   0.060521            5.78 .667 400000610
      62     7    8 0.128               0.34176   0.042667            1.65 1.0  400000620
      63     8    9 0.128               0.34176   0.042667            1.65 1.0  400000630
      64     9   10 0.128               0.34176   0.042667            1.65 1.0  400000640
      65    10   11 0.128               0.34176   0.042667            1.65 1.0  400000650
      66    11   12 0.128               0.34176   0.042667            1.65 1.0  400000660
      67     1    0 0.28928             1.874     0.0042517           3.93 .564 400000670
      68     2    0 0.23928             1.874     0.0042517           3.93 .564 400000680
      69     3    0 0.28928             1.874     0.0042517           3.93 .564 400000690
      70     4    0 0.28928             1.874     0.0042517           3.93 .564 400000700
      71     5    0 0.28928             1.874     0.0042517           3.93 .564 400000710
      72     6    0 0.28928             1.874     0.0042517           3.93 .564 400000720
      73     1    7 0.21843             0.77791   0.0040931           2.82 .550 400000730
      74     2    8 0.21843             0.77791   0.0040931           2.82 .550 400000740
      75     3    9 0.21843             0.77791   0.0040931           2.82 .550 400000750
      76     4   10 0.21843             0.77791   0.0040931           2.82 .550 400000760
      77     5   11 0.21843             0.77791   0.0040931           2.82 .550 400000770
      78     6   12 0.21843             0.77791   0.0040931           2.82 .550 400000780
      79     3 1 16 0.1888              0.18000   0.54000             0.06 0.06 600000790
      80     5 2 16 0.1888              0.18000   0.54000             0.06 0.06 600000800
      81     9 3 16 0.1888              0.18000   0.54000             0.06 0.06 600000810
      82    11 4 16 0.1888              0.18000   0.54000             0.06 0.06 600000820
      83    13   14 0.02000             0.0075    0.0075                        400000830
      84    13   15 0.009504            0.0048    0.0048                       1000000840
      85     5   13 0.0021571                                                   400000850
      86    11   13 0.0021571                                                   400000860
      87    13   16 0.000381                                                    400000870
      88  1 13 5 16 0.00117                                                     400000880
      89     2    8    1         1            0.0       0.0                      00000890
      90     3    9    1    1    1    1       0.5       0.5     0.5      0.5     00000900
      91     4   10    1         1           0.25       0.0     0.75     0.      00000910
      92     5   11         1         1       0.0       0.5     0.       0.5     00000920
      93     6   12              1            0.0       0.0     0.3      0.      00000930
      94     5   13    1                                                         00000940
      95    11   13    1                                                         00000950
      96    13   16   -1                                                         00000960
      97  1 13 5 16   -1      0.75                                               00000970
      98  0.04                                                                   00000980
      99    13   14  .41                                                         00000990
     100    13   16    1    8 .75                                                00001000
     101  1 13 5 16    1    5 2.75                                               00001010
```

Figure 2-6. Echo of the Input Data (Sheet 2 of 3)

ECHO OF THE INPUT DATA IN CARD IMAGE FORMAT

```
                  1         2         3         4         5         6         7         8
CARD NO. 12345678901234567890123456789012345678901234567890123456789012345678901234567890

   102      13   15                                                          00001020
   103       2    5    3    5.0       10.0                                   00001030
   104       3    5   13   14   16                                           00001040
   105       2    5    3    5.0       10.0                                   00001050
   106       9   11   13   14   16                                           00001060
   107       1    0    0    0    0    0    1    1    0    1                  00001070
   108       3    0    0    0    0    0    1    1    0    0                  00001080
   109      13    0    0    0    0    0    1    1    0    0                  00001090
   110      14    0    0    0    0    0    1    1    0                       00001100
   111      16    0    0    0    0    0    1    1    0    1                  00001110
   112       1   13    1    1    1    1    1                                 00001120
   113      19    1    1    1                                                00001130
   114      20    1    1    1                                                00001140
   115      19    1    1    1                                                00001150
   116      20    1    1    1                                                00001160
   117       8    1    1    1                                                00001170
   118       3    0    1    1                                                00001180
   119       4    0    1    1                                                00001190
   120       5    0    1    1                                                00001200
   121       6    0    1    1                                                00001210
   122       2    1    1                                                     00001220
   123       4    1    1                                                     00001230
   124      15                                                               00001240
   125   END                                                                 00001250
```

Figure 2-6. Echo of the Input Data (Sheet 3 of 3)

SAMPLE CASE SUBSECTIN DROP TEST SIMULATION 16MASS/32MEMBER MODEL
6-1-79 KRASH.F79.DATA 27.5 FT./SEC

PROGRAM SIZE DATA

NUMBER OF:

MASSES	SPRINGS	BEAMS	KR TABLES	NON-ZERO HE OR IXY	MASS PENETR.	VOLUME CHANGE	DRI ELEMENTS	MTL TYPES	ACCEL. TABLES	NON-STANDARD MAX. DEFL. NVB +	NON-STANDARD MAX. DEFL. NVB -	NON-STANDARD MAX. FORCE NFB +	NON-STANDARD MAX. FORCE NFB -	NON-ZERO PHI''	NON-STANDARD DAMPING	STIFFNESS MATRICES	NO. NODE PTS.
NM	NSP	NB	NLB	NHI	MVP	NVCH	NDRI	NMTL	NACC	+	-	+	-	NPH	ND	NKM	NNP
32	20	58	4	0	0	0	2	0	0	0	0	0	0	0	2	0	12

NSC= 1 NIC= 1 NTOL1= 10% NTOL2= 50% NTOL3= 100%

NO.OF OLEO STRUTS= 0 ALPHA= 0.0

PROGRAM DATA MANAGEMENT CONTROL DATA

RESTART: TITLE -
CASE - 0
TIME - 0

SAVE: TITLE -
CASE - 0
TIMES - 0 0 0 0 0

VARIABLE INTEGRATION CONTROL DATA

VAR. INT. FLAG = 0 EL = 0.0 EU = 0.0 LOWER RATIO = 0.0 UPPER RATIO = 0.0

PROGRAM CONTROL DATA

PRINT INTERVAL/ INTEGRATION INTERVAL	INTEGRATION INTERVAL	MAX. TIME	PLOW FORCE STARTING TIME	FILTER CUTOFF FREQUENCY	CASE TYPE INDICATOR
DP/DT	DT	TMAX	PLOWT	FCUT	RUNMOD
100	0.000010	0.002000	0.0	85.000	2.000

TIME HISTORY PRINT CONTROL CARDS

STRAIN FORCES	TOTAL FORCES	BEAM DEFLECTIONS	EXT.SPRING DATA	ENERGY DATA	STRESS DATA	ACCEL DATA	IMPULSE DATA
1	1	1	1	1	1	1	1

NO.OF MASS POSITION PLOTS EACH TIME= 2 PLOT PRINT FACTOR = 20

PLANE I.D.	NO.OF POINTS
2	5
2	5

VEHICLE INITIAL CONDITIONS

VEHICLE TRANSLATIONAL VELOCITIES IN GROUND AXES (IN/SEC)

Figure 2-7. Sample Case Output, Input Data (Sheet 1 of 8)

```
VEHICLE ROTATIONAL VELOCITIES IN VEHICLE AXES (RAD/SEC)
EULER ANGLES OF VEHICLE RELATIVE TO GROUND (RADIANS)

        XGDOT              YGDOT              ZGDOT
          P'                 Q'                 R'
         PHI'              THETA'              PSI'

      0.0               0.0               3.30000D 02
      0.0               0.0               0.0
      0.0               1.31000D-02       0.0

GENERALIZED SURFACE DATA

BETA =    0.0 DEGREES
XGIN =    0.0
ZGIN =    0.0
```

CORRESPONDING MASS AND BEAM NUMBERS FOR LEFT AND RIGHT SIDES OF AIRPLANE

MASSES		BEAMS									
LEFT	RIGHT	LEFT					RIGHT				
I	I	IJ	I	J	M	N	IJ	I	J	M	N
1	17	1	1	2	0	0	33	17	18	0	0
2	18	2	2	3	0	0	34	18	19	0	0
3	19	3	3	4	0	0	35	19	20	0	0
4	20	4	4	5	0	0	36	20	21	0	0
5	21	5	5	6	0	0	37	21	22	0	0
6	22	6	7	8	0	0	38	23	24	0	0
7	23	7	8	9	0	0	39	24	25	0	0
8	24	8	9	10	0	0	40	25	26	0	0
9	25	9	10	11	0	0	41	26	27	0	0
10	26	10	11	12	0	0	42	27	28	0	0
11	27	11	1	17	0	0	0	0	0	0	0
12	28	12	2	18	0	0	0	0	0	0	0
13	29	13	3	19	0	0	0	0	0	0	0
14	30	14	4	20	0	0	0	0	0	0	0
15	31	15	5	21	0	0	0	0	0	0	0
16	32	16	6	22	0	0	0	0	0	0	0
		17	1	7	0	0	43	17	23	0	0
		18	2	8	0	0	44	18	24	0	0
		19	3	9	0	0	45	19	25	0	0
		20	4	10	0	0	46	20	26	0	0
		21	5	11	0	0	47	21	27	0	0
		22	6	12	0	0	48	22	28	0	0
		23	3	16	0	1	49	19	32	0	1
		24	5	16	0	2	50	21	32	0	2
		25	9	16	0	3	51	25	32	0	3
		26	11	16	0	4	52	27	32	0	4
		27	13	14	0	0	53	29	30	0	0
		28	13	15	0	0	54	29	31	0	0
		29	5	13	0	0	55	21	29	0	0
		30	11	13	0	0	56	27	29	0	0
		31	13	16	0	0	57	29	32	0	0
		32	13	16	1	5	58	29	32	1	5

MASS DATA

Figure 2-7. Sample Case Output, Input Data (Sheet 2 of 8)

I	WEIGHTS W	MASS COORDINATES F.S.,B.L.,W.L. X''	Y''	Z''	MASS MOMENTS OF INERTIA (LB-IN-SEC**2) IX	IY	IZ	I
1	1.570000D 00	1.350000D 02	6.000000D 00	-1.600000D 01	1.350000D-01	2.380000D-02	5.100000D-02	1
2	5.030000D 00	1.400000D 02	6.000000D 00	-1.600000D 01	4.340000D-01	1.742000D-01	2.754000D-01	2
3	1.721000D 01	1.510000D 02	6.000000D 00	-1.600000D 01	4.300000D 00	4.400000D 00	5.460000D-01	3
4	7.210000D 00	1.630000D 02	6.000000D 00	-1.600000D 01	6.200000D-01	3.000000D-01	4.410000D-01	4
5	5.640000D 00	1.740000D 02	6.000000D 00	-1.600000D 01	4.860000D-01	1.990000D-01	2.960000D-01	5
6	2.200000D 00	1.810000D 02	6.000000D 00	-1.600000D 01	1.893000D-01	5.350000D-02	9.140000D-02	6
7	3.130000D 00	1.350000D 02	2.000000D 01	-1.600000D 01	1.816000D 00	1.700000D 00	1.827000D-01	7
8	1.002900D 01	1.400000D 02	2.000000D 01	-1.600000D 01	5.813000D 00	5.750000D 00	8.930000D-01	8
9	2.442000D 01	1.510000D 02	2.000000D 01	-1.600000D 01	1.215000D 01	1.220000D 01	1.600000D 00	9
10	1.442000D 01	1.630000D 02	2.000000D 01	-1.600000D 01	8.355000D 00	8.460000D 00	1.479000D 00	10
11	1.128230D 01	1.740000D 02	2.000000D 01	-1.600000D 01	6.538000D 00	7.170000D 00	1.136000D 00	11
12	4.390000D 00	1.810000D 02	2.000000D 01	-1.600000D 01	2.540000D 00	2.380000D 00	2.560000D-01	12
13	7.286000D 01	1.660000D 02	1.300000D 01	5.800000D 00	1.395110D 01	1.477420D 01	1.683410D 01	13
14	7.286000D 01	1.660000D 02	1.300000D 01	2.089000D 01	1.131160D 01	1.079890D 01	6.531800D 00	14
15	7.286000D 01	1.660000D 02	1.300000D 01	2.089000D 01	1.131160D 01	1.079890D 01	6.531800D 00	15
16	2.050000D 01	1.660000D 02	1.300000D 01	-1.700000D 00	5.950000D 00	6.606200D 00	3.152000D 00	16
17	1.570000D 00	1.350000D 02	-6.000000D 00	-1.600000D 01	1.350000D-01	2.380000D-02	5.100000D-02	17
18	5.030000D 00	1.400000D 02	-6.000000D 00	-1.600000D 01	4.340000D-01	1.742000D-01	2.754000D-01	18
19	1.721000D 01	1.510000D 02	-6.000000D 00	-1.600000D 01	4.300000D 00	4.400000D 00	5.460000D-01	19
20	7.210000D 00	1.630000D 02	-6.000000D 00	-1.600000D 01	6.200000D-01	3.000000D-01	4.410000D-01	20
21	5.640000D 00	1.740000D 02	-6.000000D 00	-1.600000D 01	4.860000D-01	1.990000D-01	2.960000D-01	21
22	2.200000D 00	1.810000D 02	-6.000000D 00	-1.600000D 01	1.893000D-01	5.350000D-02	9.140000D-02	22
23	3.130000D 00	1.350000D 02	-2.000000D 01	-1.600000D 01	1.816000D 00	1.700000D 00	1.827000D-01	23
24	1.002900D 01	1.400000D 02	-2.000000D 01	-1.600000D 01	5.813000D 00	5.750000D 00	8.930000D-01	24
25	2.442000D 01	1.510000D 02	-2.000000D 01	-1.600000D 01	1.215000D 01	1.220000D 01	1.600000D 00	25
26	1.442000D 01	1.630000D 02	-2.000000D 01	-1.600000D 01	8.355000D 00	8.460000D 00	1.479000D 00	26
27	1.128230D 01	1.740000D 02	-2.000000D 01	-1.600000D 01	6.538000D 00	7.170000D 00	1.136000D 00	27
28	4.390000D 00	1.810000D 02	-2.000000D 01	-1.600000D 01	2.540000D 00	2.380000D 00	2.560000D-01	28
29	7.286000D 01	1.660000D 02	-1.300000D 01	5.800000D 00	1.395110D 01	1.477420D 01	1.683410D 01	29
30	7.286000D 01	1.660000D 02	-1.300000D 01	2.089000D 01	1.131160D 01	1.079890D 01	6.531800D 00	30
31	7.286000D 01	1.660000D 02	-1.300000D 01	2.089000D 01	1.131160D 01	1.079890D 01	6.531800D 00	31
32	2.050000D 01	1.660000D 02	-1.300000D 01	-1.700000D 00	5.950000D 00	6.606200D 00	3.152000D 00	32

NODE POINT DATA

MASS I	N.P. M	NODE POINT COORDINATES F.S.,B.L.,W.L. X''	Y''	Z''
13	1	1.660000D 02	1.300000D 01	5.800000D 00
16	1	1.510000D 02	6.000000D 00	-1.700000D 00
16	2	1.740000D 02	6.000000D 00	-1.700000D 00
16	3	1.510000D 02	2.000000D 01	-1.700000D 00
16	4	1.740000D 02	2.000000D 01	-1.700000D 00
16	5	1.660000D 02	1.300000D 01	-1.700000D 00
29	1	1.660000D 02	-1.300000D 01	5.800000D 00
32	1	1.510000D 02	-6.000000D 00	-1.700000D 00
32	2	1.740000D 02	-6.000000D 00	-1.700000D 00
32	3	1.510000D 02	-2.000000D 01	-1.700000D 00
32	4	1.740000D 02	-2.000000D 01	-1.700000D 00
32	5	1.660000D 02	-1.300000D 01	-1.700000D 00

EXTERNAL SPRING DATA

Figure 2-7. Sample Case Output, Input Data (Sheet 3 of 8)

SPRING			FREE LENGTH	FRICTION COEFFICIENT	BOTTOMING SPRING	PLOWING FORCE	GROUND FLEXIBILITY
I	K	M	LBAR(IKM)	MU(IKM)	KE(IKM)	FORCE(IKM)	GFLEX(IKM)
2	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
3	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
4	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
5	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
6	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
8	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
9	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
10	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
11	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
12	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
18	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
19	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
20	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
21	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
22	3	0	8.000000D 00	0.0	1.000000D 04	0.0	0.0
24	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
25	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
26	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
27	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0
28	3	0	3.300000D 00	0.0	1.000000D 04	0.0	0.0

SPRING			DEFLECTION COORDINATES				SPRING AXIAL FORCES			
I	K	M	SI(IKM)	SA(IKM)	SB(IKM)	SF(IKM)	FSPOI(IKM)	FSPOF(IKM)	CRIT.DAMP	CDAMP(IKM)
2	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.290000D 03	2.290000D 03	0.0	0.0
3	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.650000D 03	2.650000D 03	0.0	0.0
4	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.650000D 03	2.650000D 03	0.0	0.0
5	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.410000D 03	2.410000D 03	0.0	0.0
6	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	1.760000D 03	1.760000D 03	0.0	0.0
8	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
9	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
10	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
11	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
12	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
18	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.290000D 03	2.290000D 03	0.0	0.0
19	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.650000D 03	2.650000D 03	0.0	0.0
20	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.650000D 03	2.650000D 03	0.0	0.0
21	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	2.410000D 03	2.410000D 03	0.0	0.0
22	3	0	1.000000D-01	5.000000D-01	7.500000D-01	4.000000D 00	1.760000D 03	1.760000D 03	0.0	0.0
24	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
25	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
26	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
27	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0
28	3	0	2.500000D-01	5.000000D-01	7.500000D-01	4.000000D 00	6.700000D 02	1.380000D 03	0.0	0.0

MATERIAL PROPERTIES

MATERIAL NO.	MODULUS OF ELASTICITY	MODULUS OF RIGIDITY	TENSION STRESS	COMPRESS. STRESS	SHEAR STRESS
1	3.0000D 07	1.1000D 07	75000.	75000.	37500.
2	3.0000D 07	1.1000D 07	205000.	205000.	80000.
3	2.8000D 07	1.2500D 07	70000.	46000.	36000.
4	1.0500D 07	4.0000D 06	47000.	39000.	22000.

Figure 2-7. Sample Case Output, Input Data (Sheet 4 of 8)

5	1.0000D 07	3.8000D 06	35000.	34000.	17000.
6	1.0000D 07	3.8000D 06	16000.	16000.	17000.
7	1.0000D 06	3.0000D 05	16000.	16000.	17000.
8	1.0000D 06	0.0	16000.	16000.	17000.
9	1.0000D 06	3.0000D 05	16000.	16000.	17000.
10	1.0000D 06	3.0000D 05	16000.	16000.	17000.

INTERNAL BEAM DATA

BEAM					AREA	MOMENTS OF INERTIA			DISTANCES FROM NEUTRAL AXIS TO EXTREME FIBRES ZBIJ AXIS	YBIJ AXIS	TORSION PARAMETER	LENGTH	DAMPING RATIO	MTL	P-CODES				BEAM				
															Y	Z	Y	Z					
IJ	I	J	M	N	A	IYY	IZZ	JX	Z1	Z2	XIQ	XLB	CBAR	MC	I	I	J	J	IJ	I	J	M	N
1	1	2	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	5.000D 00	4.000D-02	4	0	0	0	0	1	1	2	0	0
2	2	3	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.100D 01	4.000D-02	4	0	0	0	0	2	2	3	0	0
3	3	4	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	3	3	4	0	0
4	4	5	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.100D 01	4.000D-02	4	0	0	0	0	4	4	5	0	0
5	5	6	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	7.000D 00	4.000D-02	4	0	0	0	0	5	5	6	0	0
6	7	8	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	5.000D 00	4.000D-02	4	0	0	0	0	6	7	8	0	0
7	8	9	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.100D 01	4.000D-02	4	0	0	0	0	7	8	9	0	0
8	9	10	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.200D 01	4.000D-02	4	0	0	0	0	8	9	10	0	0
9	10	11	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.100D 01	4.000D-02	4	0	0	0	0	9	10	11	0	0
10	11	12	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	7.000D 00	4.000D-02	4	0	0	0	0	10	11	12	0	0
11	1	17	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	11	1	17	0	0
12	2	18	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	12	2	18	0	0
13	3	19	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	13	3	19	0	0
14	4	20	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	14	4	20	0	0
15	5	21	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	15	5	21	0	0
16	6	22	0	0	2.893D-01	1.874D 00	4.252D-03	1.878D 00	3.930D 00	5.640D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	16	6	22	0	0
17	1	7	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	0	0	0	17	1	7	0	0
18	2	8	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	0	1	0	18	2	8	0	0
19	3	9	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	1	1	1	19	3	9	0	0
20	4	10	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	0	1	0	20	4	10	0	0
21	5	11	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	1	0	1	21	5	11	0	0
22	6	12	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	0	1	0	22	6	12	0	0
23	3	16	0	1	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	23	3	16	0	1
24	5	16	0	2	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	24	5	16	0	2
25	9	16	0	3	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	25	9	16	0	3
26	11	16	0	4	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	26	11	16	0	4
27	13	14	0	0	2.000D-02	7.500D-03	7.500D-03	1.500D-02	0.0	0.0	0.0	1.509D 01	4.100D-01	4	0	0	0	0	27	13	14	0	0
28	13	15	0	0	7.197D-03	4.800D-03	4.800D-03	9.600D-03	0.0	0.0	0.0	1.509D 01	3.111D-01	10	0	0	0	0	28	13	15	0	0
29	5	13	0	0	2.157D-03	0.0	0.0	0.0	0.0	0.0	0.0	2.425D 01	4.000D-02	4	0	0	0	0	29	5	13	0	0
30	11	13	0	0	2.157D-03	0.0	0.0	0.0	0.0	0.0	0.0	2.425D 01	4.000D-02	4	0	0	0	0	30	11	13	0	0
31	13	16	0	0	3.810D-04	0.0	0.0	0.0	0.0	0.0	0.0	7.500D 00	4.000D-02	4	0	0	0	0	31	13	16	0	0
32	13	16	1	5	1.170D-03	0.0	0.0	0.0	0.0	0.0	0.0	7.500D 00	4.000D-02	4	0	0	0	0	32	13	16	1	5
33	17	18	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	5.000D 00	4.000D-02	4	0	0	0	0	33	17	18	0	0
34	18	19	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.100D 01	4.000D-02	4	0	0	0	0	34	18	19	0	0
35	19	20	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.200D 01	4.000D-02	4	0	0	0	0	35	19	20	0	0
36	20	21	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	1.100D 01	4.000D-02	4	0	0	0	0	36	20	21	0	0
37	21	22	0	0	6.157D-01	4.182D 00	6.052D-02	4.243D 00	5.780D 00	6.670D-01	0.0	7.000D 00	4.000D-02	4	0	0	0	0	37	21	22	0	0
38	23	24	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	5.000D 00	4.000D-02	4	0	0	0	0	38	23	24	0	0
39	24	25	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.100D 01	4.000D-02	4	0	0	0	0	39	24	25	0	0
40	25	26	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.200D 01	4.000D-02	4	0	0	0	0	40	25	26	0	0
41	26	27	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	1.100D 01	4.000D-02	4	0	0	0	0	41	26	27	0	0
42	27	28	0	0	1.280D-01	3.418D-01	4.267D-02	3.844D-01	1.650D 00	1.000D 00	0.0	7.000D 00	4.000D-02	4	0	0	0	0	42	27	28	0	0
43	17	23	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	0	0	0	43	17	23	0	0
44	18	24	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	0	1	0	44	18	24	0	0

Figure 2-7. Sample Case Output, Input Data (Sheet 5 of 8)

45	19	25	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	1	1	1	45	19	25	0	0
46	20	26	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	1	0	1	0	46	20	26	0	0
47	21	27	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	1	0	1	47	21	27	0	0
48	22	28	0	0	2.184D-01	7.779D-01	4.093D-03	7.820D-01	2.820D 00	5.500D-01	0.0	1.400D 01	4.000D-02	4	0	0	1	0	48	22	28	0	0
49	19	32	0	1	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	49	19	32	0	1
50	21	32	0	2	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	50	21	32	0	2
51	25	32	0	3	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	51	25	32	0	3
52	27	32	0	4	1.888D-01	1.800D-01	5.400D-01	7.200D-01	6.000D-02	6.000D-02	0.0	1.430D 01	4.000D-02	6	0	0	0	0	52	27	32	0	4
53	29	30	0	0	2.0000-02	7.500D-03	7.500D-03	1.500D-02	0.0	0.0	0.0	1.509D 01	4.100D-01	4	0	0	0	0	53	29	30	0	0
54	29	31	0	0	7.197D-03	4.800D-03	4.800D-03	9.600D-03	0.0	0.0	0.0	1.509D 01	3.111D-01	10	0	0	0	0	54	29	31	0	0
55	21	29	0	0	2.157D-03	0.0	0.0	0.0	0.0	0.0	0.0	2.425D 01	4.000D-02	4	0	0	0	0	55	21	29	0	0
56	27	29	0	0	2.157D-03	0.0	0.0	0.0	0.0	0.0	0.0	2.425D 01	4.000D-02	4	0	0	0	0	56	27	29	0	0
57	29	32	0	0	3.810D-04	0.0	0.0	0.0	0.0	0.0	0.0	7.500D 00	4.000D-02	4	0	0	0	0	57	29	32	0	0
58	29	32	1	5	1.170D-03	0.0	0.0	0.0	0.0	0.0	0.0	7.500D 00	4.000D-02	4	0	0	0	0	58	29	32	1	5

UNSYMMETRICAL BEAM DATA

BEAM					TENSION-COMPRESSION FLAG	DEADBAND
IJ	I	J	M	N	IJUB	DB
29	5	13	0	0	1	0.0
30	11	13	0	0	1	0.0
31	13	16	0	0	-1	0.0
32	13	16	1	5	-1	7.500D-01
55	21	29	0	0	1	0.0
56	27	29	0	0	1	0.0
57	29	32	0	0	-1	0.0
58	29	32	1	5	-1	7.500D-01

PLASTIC HINGE AND END-FIXITY DATA

BEAM					P-CODES	SHAPE FACTORS				PLASTIC HINGE MOMENTS			
IJ	I	J	M	N	IYIZJYJZ	SF35	SF26	SF35J	SF26J	PLM35	PLM26	PLM35J	PLM26J
18	2	8	0	0	1 0 1 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	3	9	0	0	1 1 1 1	0.500	0.500	0.500	0.500	6.483D 03	1.749D 02	6.483D 03	1.749D 02
20	4	10	0	0	1 0 1 0	0.250	0.0	0.750	0.0	3.241D 03	0.0	9.724D 03	0.0
21	5	11	0	0	0 1 0 1	0.0	0.500	0.0	0.500	0.0	1.749D 02	0.0	1.749D 02
22	6	12	0	0	0 0 1 0	0.0	0.0	0.300	0.0	0.0	0.0	3.890D 03	0.0
44	18	24	0	0	1 0 1 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	19	25	0	0	1 1 1 1	0.500	0.500	0.500	0.500	6.483D 03	1.749D 02	6.483D 03	1.749D 02
46	20	26	0	0	1 0 1 0	0.250	0.0	0.750	0.0	3.241D 03	0.0	9.724D 03	0.0
47	21	27	0	0	0 1 0 1	0.0	0.500	0.0	0.500	0.0	1.749D 02	0.0	1.749D 02
48	22	28	0	0	0 0 1 0	0.0	0.0	0.300	0.0	0.0	0.0	3.890D 03	0.0

NONLINEAR BEAM DATA

BEAM					DIRECTION	STANDARD TABLE NO.	LINEAR DEFLECTION	BOTTOMING DEFLECTION
IJ	I	J	M	N	L	NP	LDP	LDP1
31	13	16	0	0	1	8	7.50000E-01	0.0
32	13	16	1	5	1	5	2.75000E 00	0.0

Figure 2-7. Sample Case Output, Input Data (Sheet 6 of 8)

```
 57   29   32    0    0        1            8          7.50000E-01    0.0
 58   29   32    1    5        1            5          2.75000E 00    0.0

KR TABLE FOR I,J,M,N,L =    13   16    0    0   1
  1    0.0             1.00000E 00
  2    7.50000E-01     1.00000E 00
  3    7.50750E-01    -1.00000E 00
  4    1.50000E 00    -1.00000E 00
  5    1.50075E 00     0.0
  6    7.50000E 00     0.0
  7    1.12500E 01     0.0
  8    1.50000E 01     0.0

KR TABLE FOR I,J,M,N,L =    13   16    1    5   1
  1    0.0             1.00000E 00
  2    2.75000E 00     1.00000E 00
  3    2.75275E 00     0.0
  4    2.75000E 01     0.0
  5    5.50000E 01     0.0

KR TABLE FOR I,J,M,N,L =    29   32    0    0   1
  1    0.0             1.00000E 00
  2    7.50000E-01     1.00000E 00
  3    7.50750E-01    -1.00000E 00
  4    1.50000E 00    -1.00000E 00
  5    1.50075E 00     0.0
  6    7.50000E 00     0.0
  7    1.12500E 01     0.0
  8    1.50000E 01     0.0

KR TABLE FOR I,J,M,N,L =    29   32    1    5   1
  1    0.0             1.00000E 00
  2    2.75000E 00     1.00000E 00
  3    2.75275E 00     0.0
  4    2.75000E 01     0.0
  5    5.50000E 01     0.0

DPI ELEMENTS

 I  J
13 15
29 31


I,J,M,N
K-MATRIX FOR INTERNAL BEAM IJ
  1  2  0  0
   1.29292D 06   0.0           0.0           0.0           0.0           0.0
   0.0           6.10052D 04   0.0           0.0           0.0          -1.52513D 05
   0.0           0.0           4.21574D 06   0.0           1.05393D 07   0.0
   0.0           0.0           0.0           3.39424D 06   0.0           0.0
   0.0           0.0           1.05393D 07   0.0           3.51312D 07   0.0
   0.0          -1.52513D 05   0.0           0.0           0.0           5.08376D 05
  2  3  0  0
   5.87689D 05   0.0           0.0           0.0           0.0           0.0
   0.0           5.72926D 03   0.0           0.0           0.0          -3.15109D 04
   0.0           0.0           3.95916D 05   0.0           2.17755D 06   0.0
   0.0           0.0           0.0           1.54284D 06   0.0           0.0
```

Figure 2-7. Sample Case Output, Input Data (Sheet 7 of 8)

91

```
    0.0          0.0          2.17755D 06  0.0          1.59687D 07  0.0
    0.0         -3.15109D 04  0.0          0.0          0.0          2.31080D 05
  3  4  0  0
    5.38715D 05  0.0          0.0          0.0          0.0          0.0
    0.0          4.41299D 03  0.0          0.0          0.0         -2.64779D 04
    0.0          0.0          3.04958D 05  0.0          1.82975D 06  0.0
    0.0          0.0          0.0          1.41427D 06  0.0          0.0
    0.0          0.0          1.82975D 06  0.0          1.46380D 07  0.0
    0.0         -2.64779D 04  0.0          0.0          0.0          2.11824D 05
  4  5  0  0
    5.87689D 05  0.0          0.0          0.0          0.0          0.0
    0.0          5.72926D 03  0.0          0.0          0.0         -3.15109D 04
    0.0          0.0          3.95918D 05  0.0          2.17755D 06  0.0
    0.0          0.0          0.0          1.54284D 06  0.0          0.0
    0.0          0.0          2.17755D 06  0.0          1.59687D 07  0.0
    0.0         -3.15109D 04  0.0          0.0          0.0          2.31080D 05
  5  6  0  0
    9.23511D 05  0.0          0.0          0.0          0.0          0.0
    0.0          2.22322D 04  0.0          0.0          0.0         -7.78127D 04
    0.0          0.0          1.53635D 06  0.0          5.37722D 06  0.0
    0.0          0.0          0.0          2.42446D 06  0.0          0.0
    0.0          0.0          5.37722D 06  0.0          2.50937D 07  0.0
    0.0         -7.78127D 04  0.0          0.0          0.0          3.63126D 05
  7  8  0  0
    2.68800D 05  0.0          0.0          0.0          0.0          0.0
    0.0          4.30083D 04  0.0          0.0          0.0         -1.07521D 05
    0.0          0.0          3.44494D 05  0.0          8.61235D 05  0.0
    0.0          0.0          0.0          3.07542D 05  0.0          0.0
    0.0          0.0          8.61235D 05  0.0          2.87078D 06  0.0
    0.0         -1.07521D 05  0.0          0.0          0.0          3.58403D 05
  8  9  0  0
    1.22182D 05  0.0          0.0          0.0          0.0          0.0
    0.0          4.03910D 03  0.0          0.0          0.0         -2.22150D 04
    0.0          0.0          3.23529D 04  0.0          1.77941D 05  0.0
    0.0          0.0          0.0          1.39792D 05  0.0          0.0
    0.0          0.0          1.77941D 05  0.0          1.30490D 06  0.0
    0.0         -2.22150D 04  0.0          0.0          0.0          1.62910D 05
  9 10  0  0
    1.12000D 05  0.0          0.0          0.0          0.0          0.0
    0.0          3.11114D 03  0.0          0.0          0.0         -1.86668D 04
    0.0          0.0          2.49200D 04  0.0          1.49520D 05  0.0
    0.0          0.0          0.0          1.28142D 05  0.0          0.0
    0.0          0.0          1.49520D 05  0.0          1.19616D 06  0.0
    0.0         -1.86668D 04  0.0          0.0          0.0          1.49335D 05
 10 11  0  0
    1.22182D 05  0.0          0.0          0.0          0.0          0.0
    0.0          4.03910D 03  0.0          0.0          0.0         -2.22150D 04
    0.0          0.0          3.23529D 04  0.0          1.77941D 05  0.0
    0.0          0.0          0.0          1.39792D 05  0.0          0.0
    0.0          0.0          1.77941D 05  0.0          1.30490D 06  0.0
    0.0         -2.22150D 04  0.0          0.0          0.0          1.62910D 05
 11 12  0  0
    1.92000D 05  0.0          0.0          0.0          0.0          0.0
    0.0          1.56736D 04  0.0          0.0          0.0         -5.48576D 04
    0.0          0.0          1.25544D 05  0.0          4.39406D 05  0.0
    0.0          0.0          0.0          2.19673D 05  0.0          0.0
    0.0          0.0          4.39406D 05  0.0          2.05056D 06  0.0
    0.0         -5.48576D 04  0.0          0.0          0.0          2.56002D 05
  1 17  0  0
    2.53120D 05  0.0          0.0          0.0          0.0          0.0
```

Figure 2-7. Sample Case Output, Input Data (Sheet 8 of 8)

- Material properties
- Internal beam data
- Unsymmetrical beam data (optional)
- Plastic hinge and end-fixity data (optional)
- Shock strut data (optional)
- Nonlinear beam data (optional)
- Volume penetration data (optional)
- DRI elements (optional)
- Volume change data (optional)
- Non-standard maximum deflections (optional)
- Non-standard maximum forces (optional)
- Non-zero angular momenta, cross-products of inertia, lift constants (optional)
- Non-zero mass orientation Euler angles (optional)
- Acceleration input table data (optional)
- $\left[K_{ij}\right]$ matrices for all NB internal beams
- Output plot identification (optional)

The nonlinear beam data section prints out all the KR tables, whether these are user-input or standard tables coded into KRASH. Similarly, the 6 x 6 linear stiffness matrix $\left[K_{ij}\right]$ is printed for all NB internal beam elements, whether $\left[K_{ij}\right]$ is directly input by the user or internally calculated in KRASH. The printed matrix corresponds to the lower right hand quandrant of a full 12 x 12 beam stiffness matrix.

2.2.3 Model Parameters

Figure 2-8 illustrates this print for the sample case. The following sections of data are included:

- Vehicle weight
- Vehicle cg position

MODEL PARAMETERS

VEHICLE WT = 5.455026D 02

VEHICLE CG POSITION
X (FS) = 1.623620 02
Y (BL) = -7.29426D-16
Z (WL) = 7.52637D-01

VEHICLE INERTIAS (IN-LB-SEC**2)
I(XX) = 7.60483D 02
I(YY) = 5.88511D 02
I(ZZ) = 4.80857D 02

VEHICLE CG INITIAL GROUND COORDINATES
XCG IS THE DISTANCE FROM SLOPE/GROUND INTERSECTION TO VEHICLE CG,+FORWARD
ZCG IS THE DISTANCE FROM GROUND PLANE TO VEHICLE CG,+DOWN
XCG = 0.0
ZCG = -2.49957D 01

BEAM LOADS

	BEAM					AXIAL LOAD		SHEAR FORCE			MOMENT			BEAM			
IJ	I	J	M	N	BUCKLING	TENSION	COMPRESSION	LATERAL(Y)	VERTICAL(Z)	ROLL(X)	PITCH(Y)	YAW(Z)	IJ	I	J	M	N
1	1	2	0	0	1.0035D 06	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	1	1	2	0	0
2	2	3	0	0	2.0733D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	2	2	3	0	0
3	3	4	0	0	1.7422D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	3	3	4	0	0
4	4	5	0	0	2.0733D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	4	4	5	0	0
5	5	6	0	0	5.1199D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	5	5	6	0	0
6	7	8	0	0	7.0746D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	6	7	8	0	0
7	8	9	0	0	1.4617D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	7	8	9	0	0
8	9	10	0	0	1.2282D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	8	9	10	0	0
9	10	11	0	0	1.4617D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	9	10	11	0	0
10	11	12	0	0	3.6095D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	10	11	12	0	0
11	1	17	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	11	1	17	0	0
12	2	18	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	12	2	18	0	0
13	3	19	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	13	3	19	0	0
14	4	20	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	14	4	20	0	0
15	5	21	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	15	5	21	0	0
16	6	22	0	0	1.2239D 04	1.3596D 04	1.1282D 04	4.2640D 03	4.2640D 03	0.0	1.8597D 04	2.9400D 02	16	6	22	0	0
17	1	7	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	3.2197D 03	0.0	1.0758D 04	2.9024D 02	17	1	7	0	0
18	2	8	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	0.0	0.0	0.0	2.9024D 02	18	2	8	0	0
19	3	9	0	0	2.1641D 03	1.0266D 04	8.5188D 03	0.0	0.0	0.0	0.0	0.0	19	3	9	0	0
20	4	10	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	0.0	0.0	0.0	2.9024D 02	20	4	10	0	0
21	5	11	0	0	2.1641D 03	1.0266D 04	8.5188D 03	0.0	3.2197D 03	0.0	1.0758D 04	0.0	21	5	11	0	0
22	6	12	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	3.2197D 03	0.0	1.0758D 04	2.9024D 02	22	6	12	0	0
23	3	16	0	1	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	23	3	16	0	1
24	5	16	0	2	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	24	5	16	0	2
25	9	16	0	3	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	25	9	16	0	3
26	11	16	0	4	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	26	11	16	0	4
27	13	14	0	0	1.3653D 04	9.4000D 02	7.8000D 02	2.9480D 02	2.9480D 02	0.0	0.0	0.0	27	13	14	0	0
28	13	15	0	0	8.3219D 02	1.1515D 02	1.1515D 02	8.1969D 01	8.1969D 01	0.0	0.0	0.0	28	13	15	0	0
29	5	13	0	0	0.0	1.0138D 02	8.4127D 01	3.1796D 01	3.1796D 01	0.0	0.0	0.0	29	5	13	0	0
30	11	13	0	0	0.0	1.0138D 02	8.4127D 01	3.1796D 01	3.1796D 01	0.0	0.0	0.0	30	11	13	0	0
31	13	16	0	0	0.0	1.7907D 01	1.4859D 01	5.6159D 00	5.6159D 00	0.0	0.0	0.0	31	13	16	0	0
32	13	16	1	5	0.0	5.4990D 01	4.5630D 01	1.7246D 01	1.7246D 01	0.0	0.0	0.0	32	13	16	1	5

Figure 2-8. Sample Case Output, Model Parameter Data (Sheet 1 of 5)

33	17	18	0	0	1.0035D 06	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	33	17	18	0	0
34	18	19	0	0	2.0733D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	34	18	19	0	0
35	19	20	0	0	1.7422D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	35	19	20	0	0
36	20	21	0	0	2.0733D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	36	20	21	0	0
37	21	22	0	0	5.1199D 05	2.8937D 04	2.4011D 04	9.0750D 03	9.0750D 03	0.0	2.8220D 04	3.5387D 03	37	21	22	0	0
38	23	24	0	0	7.0746D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	38	23	24	0	0
39	24	25	0	0	1.4617D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	39	24	25	0	0
40	25	26	0	0	1.2282D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	40	25	26	0	0
41	26	27	0	0	1.4617D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	41	26	27	0	0
42	27	28	0	0	3.6095D 05	6.0160D 03	4.9920D 03	1.8867D 03	1.8867D 03	0.0	8.0780D 03	1.6640D 03	42	27	28	0	0
43	17	23	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	3.2197D 03	0.0	1.0758D 04	2.9024D 02	43	17	23	0	0
44	18	24	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	0.0	0.0	0.0	2.9024D 02	44	18	24	0	0
45	19	25	0	0	2.1641D 03	1.0266D 04	8.5188D 03	0.0	0.0	0.0	0.0	0.0	45	19	25	0	0
46	20	26	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	0.0	0.0	0.0	2.9024D 02	46	20	26	0	0
47	21	27	0	0	2.1641D 03	1.0266D 04	8.5188D 03	0.0	3.2197D 03	0.0	1.0758D 04	0.0	47	21	27	0	0
48	22	28	0	0	8.6566D 03	1.0266D 04	8.5188D 03	3.2197D 03	3.2197D 03	0.0	1.0758D 04	2.9024D 02	48	22	28	0	0
49	19	32	0	1	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	49	19	32	0	1
50	21	32	0	2	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	50	21	32	0	2
51	25	32	0	3	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	51	25	32	0	3
52	27	32	0	4	3.4750D 05	3.0208D 03	3.0208D 03	2.1504D 03	2.1504D 03	0.0	4.8000D 04	1.4400D 05	52	27	32	0	4
53	29	30	0	0	1.3653D 04	9.4000D 02	7.8000D 02	2.9480D 02	2.9480D 02	0.0	0.0	0.0	53	29	30	0	0
54	29	31	0	0	8.3219D 02	1.1515D 02	1.1515D 02	8.1969D 01	8.1969D 01	0.0	0.0	0.0	54	29	31	0	0
55	21	29	0	0	0.0	1.0139D 02	8.4127D 01	3.1796D 01	3.1796D 01	0.0	0.0	0.0	55	21	29	0	0
56	27	29	0	0	0.0	1.0138D 02	8.4127D 01	3.1796D 01	3.1796D 01	0.0	0.0	0.0	56	27	29	0	0
57	29	32	0	0	0.0	1.7907D 01	1.4859D 01	5.6159D 00	5.6159D 00	0.0	0.0	0.0	57	29	32	0	0
58	29	32	1	5	0.0	5.4990D 01	4.5630D 01	1.7246D 01	1.7246D 01	0.0	0.0	0.0	58	29	32	1	5

BEAM DEFLECTIONS

	BEAM					DEFLECTION			TRANSLATION DUE TO				ROTATION ABOUT	
IJ	I	J	M	N	BUCKLING	TENSION	COMPRESSION	F(Y)	F(Z)	BM(Z)	BM(Y)	X-AXIS	Y-AXIS	Z-AXIS
1	1	2	0	0	7.761D-01	2.238D-02	1.857D-02	1.488D-01	2.153D-03	4.641D-02	5.355D-03	0.0	3.213D-03	2.784D-02
2	2	3	0	0	3.528D-01	4.924D-02	4.086D-02	1.584D 00	2.292D-02	2.246D-01	2.592D-02	0.0	7.069D-03	6.126D-02
3	3	4	0	0	3.234D-01	5.371D-02	4.457D-02	2.056D 00	2.976D-02	2.673D-01	3.085D-02	0.0	7.711D-03	6.682D-02
4	4	5	0	0	3.528D-01	4.924D-02	4.086D-02	1.584D 00	2.292D-02	2.246D-01	2.592D-02	0.0	7.069D-03	6.126D-02
5	5	6	0	0	5.544D-01	3.133D-02	2.600D-02	4.082D-01	5.907D-03	9.095D-02	1.050D-02	0.0	4.498D-03	3.898D-02
6	7	8	0	0	2.632D 00	2.238D-02	1.857D-02	4.387D-02	5.477D-03	3.095D-02	1.876D-02	0.0	1.126D-02	1.857D-02
7	8	9	0	0	1.196D 00	4.924D-02	4.086D-02	4.671D-01	5.832D-02	1.498D-01	9.079D-02	0.0	2.476D-02	4.086D-02
8	9	10	0	0	1.097D 00	5.371D-02	4.457D-02	6.064D-01	7.571D-02	1.783D-01	1.081D-01	0.0	2.701D-02	4.457D-02
9	10	11	0	0	1.196D 00	4.924D-02	4.086D-02	4.671D-01	5.832D-02	1.498D-01	9.079D-02	0.0	2.476D-02	4.086D-02
10	11	12	0	0	1.880D 00	3.133D-02	2.600D-02	1.204D-01	1.503D-02	6.067D-02	3.677D-02	0.0	1.576D-02	2.600D-02
11	1	17	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
12	2	18	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
13	3	19	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
14	4	20	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
15	5	21	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
16	6	22	0	0	4.835D-02	5.371D-02	4.457D-02	1.375D 01	3.120D-02	3.161D-01	4.537D-02	0.0	1.134D-02	7.903D-02
17	1	7	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
18	2	8	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
19	3	9	0	0	1.321D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
20	4	10	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
21	5	11	0	0	1.321D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
22	6	12	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
23	3	16	0	1	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
24	5	16	0	2	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
25	9	16	0	3	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
26	11	16	0	4	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01

Figure 2-8. Sample Case Output, Model Parameter Data (Sheet 2 of 5)

27	13	14	0	0	9.811D-01	6.755D-02	5.605D-02	1.072D 00	1.072D 00	0.0	0.0	0.0	0.0	0.0
28	13	15	0	0	1.745D 00	2.414D-01	2.414D-01	4.890D 00	4.890D 00	0.0	0.0	0.0	0.0	0.0
29	5	13	0	0	0.0	1.086D-01	9.009D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	11	13	0	0	0.0	1.086D-01	9.009D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	13	16	0	0	0.0	3.357D-02	2.786D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	13	16	1	5	0.0	3.357D-02	2.786D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	17	18	0	0	7.761D-01	2.238D-02	1.857D-02	1.468D-01	2.153D-03	4.641D-02	5.355D-03	0.0	3.213D-03	2.784D-02
34	18	19	0	0	3.526D-01	4.924D-02	4.086D-02	1.584D 00	2.292D-02	2.246D-01	2.592D-02	0.0	7.069D-03	6.126D-02
35	19	20	0	0	3.234D-01	5.371D-02	4.457D-02	2.056D 00	2.976D-02	2.673D-01	3.085D-02	0.0	7.711D-03	6.682D-02
36	20	21	0	0	3.528D-01	4.924D-02	4.086D-02	1.584D 00	2.292D-02	2.246D-01	2.592D-02	0.0	7.069D-03	6.126D-02
37	21	22	0	0	5.544D-01	3.133D-02	2.600D-02	4.082D-01	5.907D-03	9.095D-02	1.050D-02	0.0	4.498D-03	3.898D-02
38	23	24	0	0	2.632D 00	2.238D-02	1.857D-02	4.387D-02	5.477D-03	3.095D-02	1.876D-02	0.0	1.126D-02	1.857D-02
39	24	25	0	0	1.196D 00	4.924D-02	4.086D-02	4.671D-01	5.832D-02	1.498D-01	9.079D-02	0.0	2.476D-02	4.086D-02
40	25	26	0	0	1.097D 00	5.371D-02	4.457D-02	6.064D-01	7.571D-02	1.783D-01	1.081D-01	0.0	2.701D-02	4.457D-02
41	26	27	0	0	1.196D 00	4.924D-02	4.086D-02	4.671D-01	5.832D-02	1.498D-01	9.079D-02	0.0	2.476D-02	4.086D-02
42	27	28	0	0	1.880D 00	3.133D-02	2.600D-02	1.204D-01	1.503D-02	6.067D-02	3.677D-02	0.0	1.576D-02	2.600D-02
43	17	23	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
44	18	24	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
45	19	25	0	0	1.321D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
46	20	26	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
47	21	27	0	0	1.321D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
48	22	28	0	0	5.284D-02	6.267D-02	5.200D-02	1.713D 01	9.014D-02	4.412D-01	8.605D-02	0.0	1.844D-02	9.455D-02
49	19	32	0	1	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
50	21	32	0	2	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
51	25	32	0	3	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
52	27	32	0	4	2.632D 00	2.288D-02	2.288D-02	9.704D-02	2.911D-01	1.818D 00	1.818D 00	0.0	3.813D-01	3.813D-01
53	29	30	0	0	9.811D-01	6.755D-02	5.605D-02	1.072D 00	1.072D 00	0.0	0.0	0.0	0.0	0.0
54	29	31	0	0	1.745D 00	2.414D-01	2.414D-01	4.890D 00	4.890D 00	0.0	0.0	0.0	0.0	0.0
55	21	29	0	0	0.0	1.086D-01	9.009D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	27	29	0	0	0.0	1.086D-01	9.009D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	29	32	0	0	0.0	3.357D-02	2.786D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58	29	32	1	5	0.0	3.357D-02	2.786D-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0

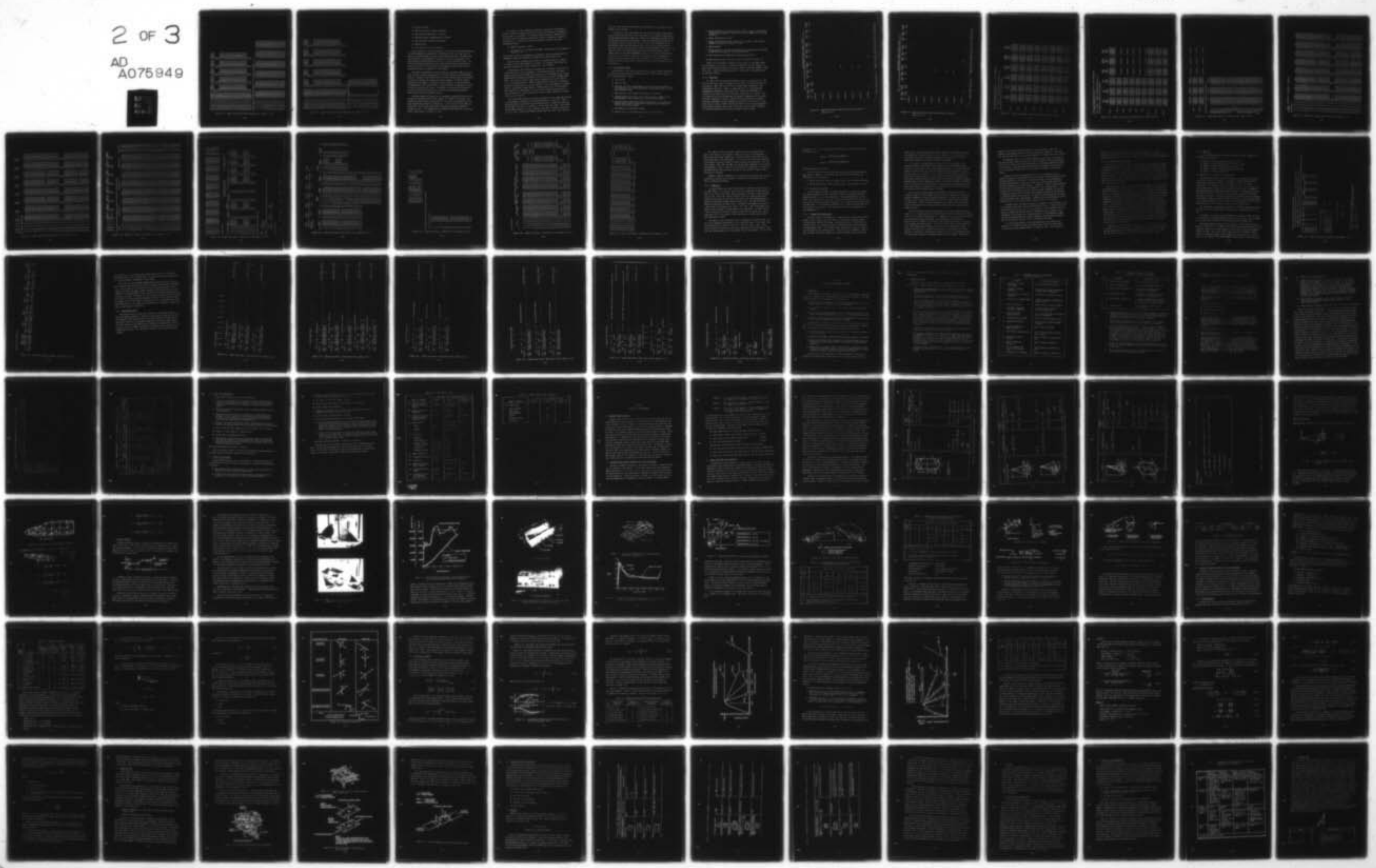
BEAM UNCOUPLED,UNDAMPED FREQUENCIES (CPS)

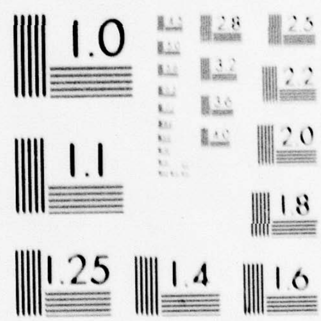
IJ	I	J	M	N	(1)	(2)	(3)	(4)	(5)	(6)
1	1	2	0	0	3.2504D 03	7.0605D 02	5.8693D 03	9.1377D 02	6.5191D 03	5.4704D 02
2	2	3	0	0	1.2150D 03	1.1997D 02	9.9726D 02	3.1486D 02	1.5537D 03	1.7881D 02
3	3	4	0	0	1.0181D 03	9.2150D 01	7.6603D 02	2.5712D 02	1.1490D 03	1.4630D 02
4	4	5	0	0	1.3475D 03	1.3305D 02	1.1060D 03	3.7874D 02	1.8387D 03	1.8179D 02
5	5	6	0	0	2.3886D 03	3.7061D 02	3.0808D 03	6.7140D 02	3.8827D 03	3.6292D 02
6	7	8	0	0	1.0496D 03	4.1986D 02	1.1883D 03	7.5032D 01	2.3542D 02	2.4466D 02
7	8	9	0	0	4.0992D 02	7.4532D 01	2.1094D 02	3.0010D 01	9.1966D 01	8.4854D 01
8	9	10	0	0	3.4754D 02	5.7924D 01	1.6394D 02	2.5606D 01	7.7878D 01	7.0155D 01
9	10	11	0	0	4.3443D 02	7.8988D 01	2.2355D 02	3.1071D 01	9.2288D 01	8.0141D 01
10	11	12	0	0	7.7073D 02	2.2021D 02	6.2323D 02	5.5152D 01	1.7049D 02	1.7618D 02
11	1	17	0	0	1.7756D 03	6.2140D 01	1.3046D 03	1.1544D 03	1.5689D 03	1.2158D 02
12	2	18	0	0	9.9199D 02	3.4717D 01	7.2886D 02	4.2670D 02	8.7500D 02	5.2320D 01
13	3	19	0	0	,5.3629D 02	1.8769D 01	3.9404D 02	8.4903D 01	2.7798D 02	3.7158D 01
14	4	20	0	0	8.2856D 02	2.8997D 01	6.0878D 02	3.2516D 02	7.3206D 02	4.1346D 01
15	5	21	0	0	9.3681D 02	3.2786D 01	6.8832D 02	3.9923D 02	8.2687D 02	5.0467D 01
16	6	22	0	0	1.5000D 03	5.2494D 01	1.1021D 03	7.6997D 02	1.3249D 03	9.0819D 01
17	1	7	0	0	1.2377D 03	4.1924D 01	5.7796D 02	4.9104D 02	6.8588D 02	8.8325D 01
18	2	8	0	0	6.9149D 02	2.3422D 01	3.2289D 02	1.8296D 02	3.8259D 02	3.8441D 01
19	3	9	0	0	3.9833D 02	1.3492D 01	1.8600D 02	4.1835D 01	1.3643D 02	2.7642D 01
20	4	10	0	0	5.7727D 02	1.9553D 01	2.6956D 02	1.3976D 02	3.2003D 02	3.0259D 01
21	5	11	0	0	6.5267D 02	2.2107D 01	3.0476D 02	1.7097D 02	3.6149D 02	3.6395D 01
22	6	12	0	0	1.0454D 03	3.5411D 01	4.8817D 02	3.2888D 02	5.7927D 02	6.7956D 01
23	3	16	0	1	3.7146D 02	1.5218D 02	8.7851D 01	1.0205D 02	6.9492D 01	1.2381D 02
24	5	16	0	2	5.4024D 02	2.2133D 02	1.2778D 02	1.3383D 02	2.5694D 02	2.9182D 02
25	9	16	0	3	3.4034D 02	1.3943D 02	8.0502D 01	6.7576D 01	5.4552D 01	9.7875D 01

Figure 2-8. Sample Case Output, Model Parameter Data (Sheet 3 of 5)

AD-A075 949 LOCKHEED-CALIFORNIA CO BURBANK F/G 1/3
GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS USER'S MAN--ETC(U)
SEP 79 M A GAMON , G WITTLIN , W L LABARGE DOT-FA75WA-3707
UNCLASSIFIED LR-28307-VOL-2 FAA/RD-77/189-V2-REV NL

2 OF 3
AD
A075949





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

26	11	16	0	4	4.2118D 02	1.7255D 02	9.9622D 01	7.6183D 01	6.0904D 01	1.1083D 02
27	13	14	0	0	6.1115D 01	8.5914D 00	8.5914D 00	4.6263D 00	9.2062D 00	9.2004D 00
28	13	15	0	0	1.1314D 01	2.1211D 00	2.1211D 00	1.0136D 00	2.2729D 00	2.2714D 00
29	5	13	0	0	4.1764D 01	0.0	0.0	0.0	0.0	0.0
30	11	13	0	0	3.0572D 01	0.0	0.0	0.0	0.0	0.0
31	13	16	0	0	1.8055D 01	0.0	0.0	0.0	0.0	0.0
32	13	16	1	5	3.1640D 01	0.0	0.0	0.0	0.0	0.0
33	17	18	0	0	3.2504D 03	7.0605D 02	5.8693D 03	9.1377D 02	6.5191D 03	5.4704D 02
34	18	19	0	0	1.2150D 03	1.1997D 02	9.9726D 02	3.1486D 02	1.5537D 03	1.7891D 02
35	19	20	0	0	1.0181D 03	9.2150D 01	7.6603D 02	2.5712D 02	1.1490D 03	1.4839D 02
36	20	21	0	0	1.3475D 03	1.3305D 02	1.1060D 03	3.7874D 02	1.8387D 03	1.8179D 02
37	21	22	0	0	2.3886D 03	3.7061D 02	3.0808D 03	6.7140D 02	3.8827D 03	3.6292D 02
38	23	24	0	0	1.0496D 03	4.1986D 02	1.1883D 03	7.5032D 01	2.3542D 02	2.4466D 02
39	24	25	0	0	4.0992D 02	7.4532D 01	2.1094D 02	3.0010D 01	9.1966D 01	8.4854D 01
40	25	26	0	0	3.4754D 02	5.7924D 01	1.6394D 02	2.5606D 01	7.7878D 01	7.0155D 01
41	26	27	0	0	4.3443D 02	7.8989D 01	2.2355D 02	3.1071D 01	9.2289D 01	8.0141D 01
42	27	28	0	0	7.7073D 02	2.2021D 02	6.2323D 02	5.5152D 01	1.7049D 02	1.7618D 02
43	17	23	0	0	1.2377D 03	4.1924D 01	5.7796D 02	4.9104D 02	6.8586D 02	8.8325D 01
44	18	24	0	0	6.9149D 02	2.3422D 01	3.2289D 02	1.8296D 02	3.8259D 02	3.8441D 01
45	19	25	0	0	3.9833D 02	1.3492D 01	1.8600D 02	4.1835D 01	1.3643D 02	2.7642D 01
46	20	26	0	0	5.7727D 02	1.9553D 01	2.6956D 02	1.3976D 02	3.2003D 02	3.0259D 01
47	21	27	0	0	6.5267D 02	2.2107D 01	3.0476D 02	1.7097D 02	3.6149D 02	3.6395D 01
48	22	28	0	0	1.0454D 03	3.5411D 01	4.8817D 02	3.2888D 02	5.7927D 02	6.7956D 01
49	19	32	0	1	3.7146D 02	1.5218D 02	8.7861D 01	1.0205D 02	6.9492D 01	1.2381D 02
50	21	32	0	2	5.4024D 02	2.2133D 02	1.2778D 02	1.3383D 02	2.5694D 02	2.9182D 02
51	25	32	0	3	3.4034D 02	1.3943D 02	8.0502D 01	6.7576D 01	5.4552D 01	9.7875D 01
52	27	32	0	4	4.2118D 02	1.7255D 02	9.9622D 01	7.6183D 01	6.0904D 01	1.1083D 02
53	29	30	0	0	6.1115D 01	8.5914D 00	8.5914D 00	4.6263D 00	9.2062D 00	9.2004D 00
54	29	31	0	0	1.1314D 01	2.1211D 00	2.1211D 00	1.0136D 00	2.2729D 00	2.2714D 00
55	21	29	0	0	4.1764D 01	0.0	0.0	0.0	0.0	0.0
56	27	29	0	0	3.0572D 01	0.0	0.0	0.0	0.0	0.0
57	29	32	0	0	1.8055D 01	0.0	0.0	0.0	0.0	0.0
58	29	32	1	5	3.1640D 01	0.0	0.0	0.0	0.0	0.0

DAMPING TERMS (LB/IN/SEC,TRANSLATIONS (1)-(3) AND LB-IN-SEC,ROTATIONS (4)-(6))

IJ	I	J	M	N	(1)	(2)	(3)	(4)	(5)	(6)
1	1	2	0	0	3.91718D-06	1.80333D-05	2.16931D-06	1.39340D-05	1.95310D-06	2.32750D-05
2	2	3	0	0	1.04792D-05	1.06134D-04	1.27673D-05	4.04385D-05	8.19498D-06	7.12049D-05
3	3	4	0	0	1.25055D-05	1.38170D-04	1.66212D-05	4.95190D-05	1.10812D-05	8.58539D-05
4	4	5	0	0	9.44883D-06	9.56980D-05	1.15120D-05	3.36176D-05	6.92456D-06	7.00390D-05
5	5	6	0	0	5.33050D-06	3.43556D-05	4.13280D-06	1.89639D-05	3.27930D-06	3.50833D-05
6	7	8	0	0	1.21303D-05	3.03256D-05	1.07151D-05	1.69692D-04	5.40841D-05	5.20420D-05
7	8	9	0	0	3.10604D-05	1.70831D-04	6.03605D-05	4.24276D-04	1.38447D-04	1.50051D-04
8	9	10	0	0	3.66356D-05	2.19813D-04	7.76673D-05	4.97250D-04	1.63492D-04	1.81489D-04
9	10	11	0	0	2.93082D-05	1.61194D-04	5.69554D-05	4.09783D-04	1.37964D-04	1.58874D-04
10	11	12	0	0	1.65200D-05	5.78198D-05	2.04297D-05	2.30859D-04	7.46793D-05	7.22700D-05
11	1	17	0	0	7.17081D-06	2.04897D-04	9.75962D-06	1.10293D-05	8.11565D-06	1.04724D-04
12	2	18	0	0	1.28352D-05	3.66750D-04	1.74690D-05	2.98389D-05	1.45513D-05	2.43356D-04
13	3	19	0	0	2.37415D-05	6.78386D-04	3.23127D-05	1.49963D-04	4.58026D-05	3.42654D-04
14	4	20	0	0	1.53669D-05	4.39091D-04	2.09147D-05	3.91579D-05	1.73921D-05	3.07949D-04
15	5	21	0	0	1.35912D-05	3.88353D-04	1.84979D-05	3.18923D-05	1.53984D-05	2.52293D-04
16	6	22	0	0	8.48847D-06	2.42548D-04	1.15530D-05	1.65362D-05	9.61018D-06	1.40195D-04
17	1	7	0	0	1.02869D-05	3.03704D-04	2.20298D-05	2.59292D-05	1.85635D-05	1.44154D-04
18	2	8	0	0	1.84130D-05	5.43615D-04	3.94324D-05	6.95926D-05	3.32793D-05	3.31219D-04
19	3	9	0	0	3.19646D-05	9.43707D-04	6.84539D-05	3.04349D-04	9.33263D-05	4.60622D-04
20	4	10	0	0	2.20562D-05	6.51177D-04	4.72346D-05	9.10990D-05	3.97847D-05	4.20781D-04
21	5	11	0	0	1.95082D-05	5.75951D-04	4.17779D-05	7.44735D-05	3.52219D-05	3.49838D-04
22	6	12	0	0	1.21790D-05	3.59565D-04	2.60819D-05	3.87141D-05	2.19802D-05	1.87362D-04
23	3	16	0	1	3.42770D-05	8.36666D-05	1.44915D-04	1.24769D-04	1.83221D-04	1.02840D-04
24	5	16	0	2	2.35682D-05	5.75276D-05	9.96408D-05	9.51383D-05	4.95534D-05	4.36315D-05

Figure 2-8. Sample Case Output, Model Parameter Data (Sheet 4 of 5)

25	9	16	0	3	3.741050-05	9.131510-05	1.581620-04	1.884150-04	2.333980-04	1.300880-04
26	11	16	0	4	3.023060-05	7.378970-05	1.278080-04	1.671300-04	2.090560-04	1.148860-04
27	13	14	0	0	2.135430-03	1.519030-02	1.519030-02	2.821000-02	1.417600-02	1.418500-02
28	13	15	0	0	8.753550-03	4.669020-02	4.669020-02	9.770930-02	4.357240-02	4.360010-02
29	5	13	0	0	3.048630-04	0.0	0.0	0.0	0.0	0.0
30	11	13	0	0	4.164770-04	0.0	0.0	0.0	0.0	0.0
31	13	16	0	0	7.051980-04	0.0	0.0	0.0	0.0	0.0
32	13	16	1	5	4.024210-04	0.0	0.0	0.0	0.0	0.0
33	17	18	0	0	3.917180-06	1.303330-05	2.169310-06	1.393400-05	1.953100-06	2.327500-05
34	18	19	0	0	1.047920-05	1.061340-04	1.276730-05	4.043850-05	8.194980-06	7.120490-05
35	19	20	0	0	1.250550-05	1.381700-04	1.662120-05	4.951900-05	1.108120-05	8.585390-05
36	20	21	0	0	9.448830-06	9.569800-05	1.151200-05	3.361760-05	6.924560-06	7.003900-05
37	21	22	0	0	5.330500-06	3.435560-05	4.132800-06	1.896390-05	3.279300-06	3.508330-05
38	23	24	0	0	1.213030-05	3.032560-05	1.071510-05	1.696920-04	5.408410-05	5.204200-05
39	24	25	0	0	3.106040-05	1.708310-04	6.036050-05	4.242760-04	1.304470-04	1.500510-04
40	25	26	0	0	3.663560-05	2.198130-04	7.766730-05	4.972500-04	1.634920-04	1.814890-04
41	26	27	0	0	2.930820-05	1.611940-04	5.695540-05	4.097830-04	1.379640-04	1.588740-04
42	27	28	0	0	1.652000-05	5.781980-05	2.042970-05	2.308590-04	7.467930-05	7.227000-05
43	17	23	0	0	1.028690-05	3.037040-04	2.202980-05	2.592920-05	1.856350-05	1.441540-04
44	18	24	0	0	1.841300-05	5.436150-04	3.943240-05	6.959260-05	3.327930-05	3.312190-04
45	19	25	0	0	3.196460-05	9.437070-04	6.845390-05	3.043490-04	9.332630-05	4.606220-04
46	20	26	0	0	2.205620-05	6.511770-04	4.723460-05	9.109900-05	3.978470-05	4.207810-04
47	21	27	0	0	1.950820-05	5.759510-04	4.177790-05	7.447350-05	3.522190-05	3.498380-04
48	22	28	0	0	1.217900-05	3.595650-04	2.608190-05	3.871410-05	2.198020-05	1.873620-04
49	19	32	0	1	3.427700-05	8.366660-05	1.449150-04	1.247690-04	1.832210-04	1.028400-04
50	21	32	0	2	2.356820-05	5.752760-05	9.964080-05	9.513830-05	4.955340-05	4.363150-05
51	25	32	0	3	3.741050-05	9.131510-05	1.581620-04	1.884150-04	2.333980-04	1.300880-04
52	27	32	0	4	3.023060-05	7.378970-05	1.278080-04	1.671300-04	2.090560-04	1.148860-04
53	29	30	0	0	2.135430-03	1.519030-02	1.519030-02	2.821000-02	1.417600-02	1.418500-02
54	29	31	0	0	8.753550-03	4.669020-02	4.669020-02	9.770930-02	4.357240-02	4.360010-02
55	21	29	0	0	3.048630-04	0.0	0.0	0.0	0.0	0.0
56	27	29	0	0	4.164770-04	0.0	0.0	0.0	0.0	0.0
57	29	32	0	0	7.051980-04	0.0	0.0	0.0	0.0	0.0
58	29	32	1	5	4.024210-04	0.0	0.0	0.0	0.0	0.0

EULER ANGLES, BEAM IJ TO AIRPLANE (RADIANS)

IJ	I	J	M	N	THEIJ0(IJ)	PSIIJ0(IJ)
1	1	2	0	0	0.0	3.141590 00
2	2	3	0	0	0.0	3.141590 00
3	3	4	0	0	0.0	3.141590 00
4	4	5	0	0	0.0	3.141590 00
5	5	6	0	0	0.0	3.141590 00
6	7	8	0	0	0.0	3.141590 00
7	8	9	0	0	0.0	3.141590 00
8	9	10	0	0	0.0	3.141590 00
9	10	11	0	0	0.0	3.141590 00
10	11	12	0	0	0.0	3.141590 00
11	1	17	0	0	0.0	1.570800 00
12	2	18	0	0	0.0	1.570800 00
13	3	19	0	0	0.0	1.570800 00
14	4	20	0	0	0.0	1.570800 00
15	5	21	0	0	0.0	1.570800 00
16	6	22	0	0	0.0	1.570800 00
17	1	7	0	0	0.0	-1.570800 00
18	2	8	0	0	0.0	-1.570800 00
19	3	9	0	0	0.0	-1.570800 00
20	4	10	0	0	0.0	-1.570800 00
21	5	11	0	0	0.0	-1.570800 00
22	6	12	0	0	0.0	-1.570800 00
23	3	16	0	1	1.570800 00	0.0

Figure 2-8. Sample Case Output, Model Parameter Data (Sheet 5 of 5)

- Vehicle inertias
- Vehicle cg initial ground coordinates
- Beam loads corresponding to yielding
- Beam deflections corresponding to yielding
- Beam uncoupled, undamped frequencies
- Damping terms
- Euler angles, beam ij to airplane

These quantities are all calculated in the Initial Conditions subroutine. The vehicle weight, cg position and inertias are used to see how well the analytical model matches the actual vehicle being analyzed. The beam loads and deflections corresponding to yielding are utilized as guidelines for establishing nonlinear deflection points for internal beam KR curves. The loads are calculated using the stress and buckling equations discussed in Volume I Section 1.3.17, along with the appropriate yield stress for the beam material given in Table 2-2 of this report.

The loads corresponding to yield stress are uncoupled loads; e.g., the shear forces are those corresponding to yielding without any bending moment applied. Similarly, beam deflections are those resulting from the corresponding load only without the coupled load being applied. In actual loading situations, some degree of coupling is always present, so the deflections corresponding to yield provide only a rough indication of appropriate values to use for setting up KR curves. Furthermore, no attempt has been made to include in the analysis the effects of stress concentrations, geometric shape factors and end attachment details.

The beam frequencies output are the undamped, uncoupled individual beam frequencies associated with the six degrees of freedom of each beam. The frequencies listed under the headings (1), (2), and (3) correspond with the three translational degrees of freedom (x, y, z) and those listed under the heading (4), (5), and (6) correspond to the three rotational degrees of freedom (ϕ, θ, ψ). The frequencies are computed using Equations 1-55(a) and 1-55(b) from Volume I, Section 1.3.5.3.6.

The frequency values summarized should be reviewed for indications of potential stability problems which may occur with the numerical integration routine used in the program. For example, high frequencies combined with a relatively coarse integration interval may result in numerical integration instabilities. In general, beam member frequencies should satify the following criteria:

1) Member frequencies < 500 Hz

2) The product of the maximum beam member frequency and the integration interval < 0.01

While these criteria are suggested as guidelines, their exceedance does not necessarily mean that instability problems will automatically occur.

Beam structural damping coefficients are computed within the program for each of the six beam degrees of freedom. The damping coefficients are computed from Equations (1-54), Section 1.3.5.3.6, Volume I.

These damping coefficients are printed only to provide a record of the actual data used in the calculations. The interpretation of the proper damping values should be based upon inspection of the damping ratios (actual damping/critical damping) summarized in the section entitled "INTERNAL BEAM DATA". For typical aircraft constructions, damping raios in the range of .01 to .10 are appropriate. Higher values should be used only to represent mechanical damping devices, such as hydraulic or friction dampers in landing gears or viscoelastic engine mounts. Values greater than .05 are probably only justified as representative of the friction damping associated with relative motions of riveted and bolted structure under conditions of severe loading and deformation.

The Euler angles define the initial orientation of the beam axes relative to the airplane, according to the convention shown in Figure 2-2. These angles should be interpreted in the following manner. Assume the beam axes are oriented such that x is forward, y to the right and z down. Then rotate PSIIJO radians about the z axis, positive nose right, forming a new set of x' and y' axes. Then rotate THEIJO radians about the new y' axis, positive

nose up. This final position defines the orientation of the beam axes with respect to the airplane.

It should be noted that during the time history analysis, these angles vary with time and are part of the print output. Any question regarding the current beam orientations should be resolved by examining the current values of the beam orientation Euler angles. These are interpreted the same as the preceding discussion, except that the initial starting orientation is the ground axes rather than the airplane axes. Since the initial attitude of the vehicle may not be parallel to the ground axes (generally it is not), the time zero value of the beam orientation Euler angles may differ from the angles listed in the MODEL PARAMETERS section of the output. The latter is provided as a definition of beam axes orientations that is independent of vehicle initial conditions (and hence represents a true model parameter), whereas the time varying values represent the actual beam orientation during the analysis.

2.2.4 Time History Output

This section of the output prints the time varying response quantities at each print time interval, including time zero. This output consists of the following groups of data:

- Title cards
- Analysis time
- Mass and node point displacements, velocities and accelerations in six directions for all NM lumped masses and NNP node points, in mass axes and ground axes
- Mass impulses (G-sec) based on filtered accelerations
- Internal beam strain forces, total forces (strain + damping) and displacements in six directions for all NB internal beams
- External spring compressions, ground deflections, axial loads, and ground contact loads (3 directions) in ground axes and mass axes for all NSP external springs
- DRI number for all DRI beam elements
- Overall vehicle cg translational velocity (3 directions)

/()

- Volume change data, including current volume, current volume/initial volume, and the changes in length of the three lengths of the volume (optional)
- Energy distribution by type
- Energy distribution by mass (kinetic and potential), beam (strain, damping) and spring (crushing, friction)
- Mass deviation
- Stress output for internal beam elements, including ratios of current stress/failure stress for two failure theories
- Mass location plot (time=0 and at specified intervals)

The mass location plots for time = 0 are illustrated in Figure 2-9.

Figure 2-10 illustrates a portion of this output for the sample case, for one typical cut in time. It should be noted that all this output is in inch, pound, second and radian units except XACCEL, YACCEL and ZACCEL. These are in g's. A more detailed description of the specific items printed out at each time follows.

2.2.4.1 Mass Data

X, Y and Z are the ground coordinates of mass i or node point iM. The data for each node point is printed below the data for the mass to which it is attached. XDOT, YDOT and ZDOT are the ground axes components of the translational velocity of mass i or node point iM. U, V and W are the corresponding components i mass fixed axes. UDOT, VDOT and WDOT (not printed for the node points) are the time derivatives of U, V and W. Note that these are not the translational acceleration components, but are used in Euler's equations of motion. XACCEL, YACCEL and ZACCEL are the body-fixed-axes components of the translational accelerations of mass i or node point iM, in g units. XACFIL, YACFIL and ZACFIL are the same accelerations after passing through a first order filter with an input cutoff frequency. All the above quantities are positive forward, right and down.

MASS POSITION PLOT PLANE ** X(+AFT) - Z(+UP)

NOTE *** A MODIFIED RIGHT HAND GROUND COORDINATE SYSTEM HAS BEEN USED FOR THIS PLOT ***

MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS
3	-11.58	8.39	5	11.42	8.09	13	3.70	29.99	14	3.90	45.08
16	3.61	22.50									

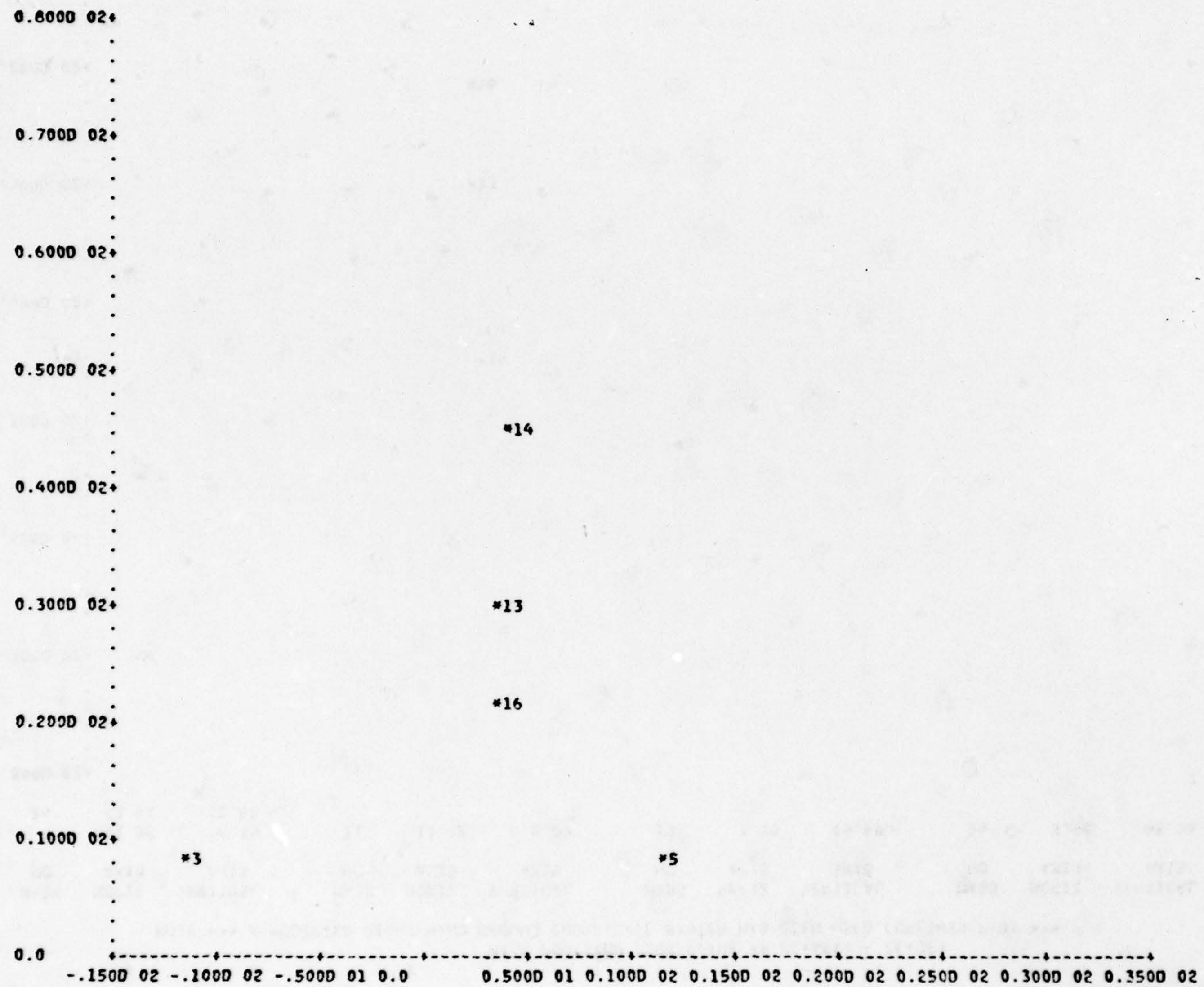


Figure 2-9. Sample Case Output, Mass Location Plots at Time = 0 (Sheet 1 of 2)

MASS POSITION PLOT PLANE ** X(+AFT) - Z(+UP)

NOTE *** A MODIFIED RIGHT HAND GROUND COORDINATE SYSTEM HAS BEEN USED FOR THIS PLOT ***

MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS	MASS NO	HORIZ AXIS	VERTICAL AXIS
9	-11.58	8.39	11	11.42	8.09	13	3.70	29.99	14	3.90	45.08
16	3.61	22.50									

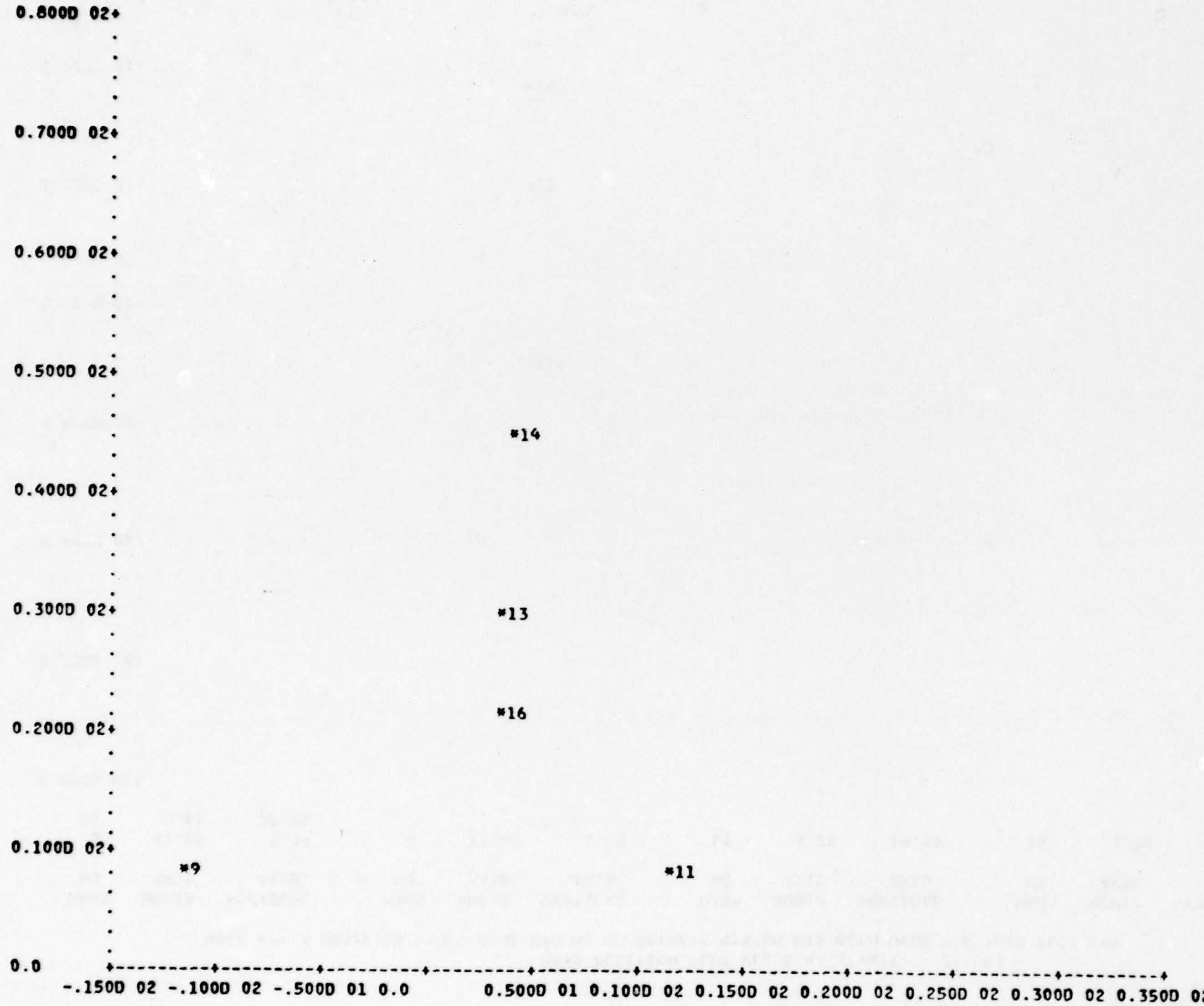


Figure 2-9. Sample Case Output, Mass Location Plots at Time = 0 (Sheet 2 of 2)

SAMPLE CASE SUBSECTIN DROP TEST SIMULATION 16MASS/32MEMBER MODEL
6-1-79 KRASH.F79.DATA 27.5 FT./SEC

TIME = 0.002000 NUMBER OF INTEGRATION INTERVALS = 100

MASS DISPLACEMENTS,VELOCITIES,AND ACCELERATIONS

	X XDOT U UDOT XACCEL	Y YDOT V VDOT YACCEL	Z ZDOT W WDOT ZACCEL	PHI PHIDOT P PDOT XACFIL	THETA THETADOT Q QDOT YACFIL	PSI PSIDOT R RDOT ZACFIL
MASS 1	2.75772D 01	-5.99998D 00	-7.94164D 00	6.26744D-05	1.12912D-02	2.60324D-06
	-3.20361D 00	3.56141D-02	3.09411D 02	-3.13617D-01	-3.14325D 00	-8.41820D-03
	-6.69668D 00	5.51043D-02	3.09357D 02	-3.13502D-01	-3.14313D 00	-8.21968D-03
	-2.72694D 03	-1.37830D 02	-1.43539D 05	-4.72841D 03	1.55051D 04	-1.02989D 02
	-9.58372D 00	-1.05661D-01	-3.71916D 02	-3.28732D 00	1.56740D-02	-2.90254D 01
MASS 2	2.25776D 01	-5.99987D 00	-7.88495D 00	1.25823D-05	1.14631D-02	-3.72871D-06
	-3.33432D 00	3.83038D-02	2.95022D 02	2.83217D-02	-2.69330D 00	-1.68067D-02
	-6.71569D 00	4.20108D-02	2.94963D 02	2.85026D-02	-2.69337D 00	-1.67715D-02
	-2.84666D 03	-3.97541D 01	-7.87167D 04	-4.51564D 02	9.94025D 03	-3.43996D 01
	-9.43286D 00	-1.24487D-01	-2.03976D 02	-3.22027D 00	1.58672D-02	-4.31705D 01
MASS 3	1.15785D 01	-5.99944D 00	-7.75645D 00	-1.63094D-04	1.16347D-02	-1.44640D-05
	-3.67591D 00	7.79267D-01	2.71531D 02	-6.89341D-01	-3.05331D 00	-5.05092D-02
	-6.83481D 00	7.34971D-01	2.71471D 02	-6.88753D-01	-3.05329D 00	-5.10034D-02
	-2.80653D 03	-1.76353D 01	-7.08652D 04	-1.86072D 03	-1.63494D 03	-1.40183D 02
	-9.41808D 00	4.39610D-01	-1.83644D 02	-3.23884D 00	7.82699D-01	-6.58130D 01
MASS 4	-4.20774D-01	-5.99986D 00	-7.62875D 00	-1.66548D-03	1.03352D-02	-2.54438D-05
	-3.35680D 00	8.47180D-02	2.64224D 02	-2.13301D-01	1.24753D 00	-2.24650D-02
	-6.08760D 00	-3.55465D-01	2.64173D 02	-2.13093D-01	1.24792D 00	-2.03855D-02
	-4.95933D 03	1.54305D 02	-2.39466D 04	6.81374D 03	-1.41669D 04	4.69319D 01
	-1.19942D 01	5.45899D-01	-6.20180D 01	-2.78632D 00	1.17651D-01	-6.11318D 01
MASS 5	-1.14203D 01	-5.99861D 00	-7.51921D 00	-1.72817D-03	9.46388D-03	-6.77062D-06
	-3.10087D 00	1.23920D 00	2.68892D 02	6.41095D-01	-5.75047D-01	1.99659D-02
	-5.64533D 00	7.74524D-01	2.68853D 02	6.40895D-01	-5.75302D-01	1.89707D-02
	-3.66601D 03	4.63449D 02	-9.76928D 04	1.29210D 03	7.94435D 03	-2.62751D 01
	-9.89801D 00	7.53972D-01	-2.53097D 02	-2.38138D 00	9.99485D-01	-4.02364D 01
MASS 6	-1.84199D 01	-5.99975D 00	-7.45538D 00	-2.10339D-03	8.95198D-03	1.99839D-04
	-3.08974D 00	1.78398D-01	2.61524D 02	3.61269D-01	-1.43623D 00	4.64279D-01
	-5.43036D 00	-3.71030D-01	2.61486D 02	3.57106D-01	-1.43762D 00	4.61238D-01
	-4.45540D 03	5.16101D 01	-7.29932D 03	2.17339D 03	1.70656D 04	1.73501D 02
	-1.25156D 01	-1.14702D-01	-1.89307D 01	-2.24958D 00	1.44671D-01	-3.92336D 01
MASS 7	2.75783D 01	-1.99996D 01	-7.94145D 00	1.73870D-05	1.30965D-02	1.06090D-05
	-4.86516D-01	1.34323D-01	3.32062D 02	6.53999D-02	-6.03923D-02	4.04172D-03
	-4.83520D 00	1.40104D-01	3.32027D 02	6.53418D-02	-6.08897D-02	4.04176D-03
	-7.97249D 02	-9.96861D 00	-4.75839D 03	-1.33897D 02	-2.45835D 02	-4.14704D 01
	-2.11779D 00	-8.25159D-02	-1.23282D 01	-5.40812D-01	8.16177D-02	2.04878D 00
MASS 8	2.25788D 01	-1.99996D 01	-7.87596D 00	7.81048D-08	1.31128D-02	1.22571D-06
	-5.04416D-01	1.22053D-01	3.32793D 02	-1.00433D-05	2.35402D-02	-5.49571D-03
	-4.86810D 00	1.22080D-01	3.32759D 02	6.19931D-05	2.35406D-02	-5.49523D-03
	-9.10165D 02	-1.21385D 02	4.07864D 03	-6.30464D-01	9.86836D 00	-2.23163D 01
	-2.33765D 00	-3.14452D-01	1.05667D 01	-5.87153D-01	4.59835D-02	3.07041D 00

Figure 2-10. Sample Case Output, Time History Print (Sheet 1 of 11)

SAMPLE CASE SUBSECTIN DROP TEST SIMULATION 16MASS/32MEMBER MODEL
6-1-79 KRASH.F79.DATA 27.5 FT./SEC

TIME = 0.002000 NUMBER OF INTEGRATION INTERVALS = 100

MASS DISPLACEMENTS,VELOCITIES,AND ACCELERATIONS

	X XDOT U UDOT XACCEL	Y YDOT V VDOT YACCEL	Z ZDOT W WDOT ZACCEL	PHI PHIDOT P PDOT XACFIL	THETA THETADOT Q QDOT YACFIL	FSI PSIDOT R RDOT ZACFIL
MASS 16	-3.60106D 00	-1.30068D 01	-2.18786D 01	-2.19720D-03	1.06316D-02	-7.27051D-05
	9.44574D 00	-1.51339D 01	2.69721D 02	-2.75550D 00	-2.17955D 00	-1.04211D-01
	6.57883D 00	-1.57260D 01	2.69772D 02	-2.75440D 00	-2.17933D 00	-1.08993D-01
	1.42792D 04	-2.15792D 04	-1.60695D 04	-3.24146D 02	3.06913D 03	-3.43895D 02
	3.54653D 01	-5.39814D 01	-4.14814D 01	1.09184D 01	-1.66148D 01	-5.80126D 01
NODE 1	1.13984D 01	-6.00791D 00	-2.20534D 01			
	1.03511D 01	-1.67394D 01	2.83125D 02			
	7.34178D 00	-1.73609D 01	2.83181D 02			
	4.16255D 01	-6.72497D 01	-1.66610D 02	1.16434D 01	-1.82428D 01	-5.12908D 01
NODE 2	-1.16003D 01	-6.00624D 00	-2.18089D 01			
	9.81834D 00	-1.43427D 01	2.32997D 02			
	7.34178D 00	-1.48541D 01	2.33057D 02			
	4.19092D 01	-4.71163D 01	1.62473D 01	1.17812D 01	-1.58006D 01	-8.83781D 01
NODE 3	1.13977D 01	-2.00079D 01	-2.20226D 01			
	9.23526D 00	-1.66546D 01	3.21700D 02			
	5.81588D 00	-1.73609D 01	3.21743D 02			
	2.89349D 01	-6.69741D 01	-1.54862D 02	1.00047D 01	-1.81723D 01	-1.56725D 01
NODE 4	-1.16010D 01	-2.00062D 01	-2.17781D 01			
	8.70249D 00	-1.42579D 01	2.71573D 02			
	5.81588D 00	-1.48541D 01	2.71618D 02			
	2.92187D 01	-4.68407D 01	2.79953D 01	1.01425D 01	-1.57301D 01	-5.27597D 01
NODE 5	-3.60106D 00	-1.30068D 01	-2.18786D 01			
	9.44573D 00	-1.51339D 01	2.69721D 02			
	6.57883D 00	-1.57260D 01	2.69772D 02			
	3.54653D 01	-5.39814D 01	-4.14814D 01	1.09139D 01	-1.66148D 01	-5.76690D 01
MASS 17	2.75772D 01	5.99988D 00	-7.94164D 00	-6.26744D-05	1.12912D-02	-2.60324D-06
	-3.20361D 00	-3.56141D-02	3.09411D 02	3.13617D-01	-3.14325D 00	8.41820D-03
	-6.69668D 00	-5.51043D-02	3.09357D 02	3.13502D-01	-3.14313D 00	8.21968D-03
	-2.72694D 03	1.37830D 02	-1.43539D 05	4.72841D 03	1.55051D 04	1.02989D 02
	-9.58372D 00	1.05661D-01	-3.71916D 02	-3.28732D 00	-1.56740D-02	-2.90254D 01
MASS 18	2.25776D 01	5.99987D 00	-7.88495D 00	-1.25823D-05	1.14631D-02	3.72871D-06
	-3.33432D 00	-3.83030D-02	2.95022D 02	-2.83217D-02	-2.69330D 00	1.68067D-02
	-6.71569D 00	-4.20103D-02	2.94953D 02	-2.85026D-02	-2.69337D 00	1.67715D-02
	-2.84666D 03	3.97541D 01	-7.87167D 04	4.51564D 02	9.94025D 03	3.43976D 01
	-9.43286D 00	1.24487D-01	-2.03976D 02	-3.22027D 00	-1.50672D-02	-4.31705D 01
MASS 19	1.15785D 01	5.99944D 00	-7.75645D 00	1.63094D-04	1.16347D-02	1.44640D-05
	-3.67591D 00	-7.79267D-01	2.71531D 02	6.89341D-01	-3.05331D 00	5.05092D-02
	-6.83481D 00	-7.34971D-01	2.71471D 02	6.88753D-01	-3.05329D 00	5.10034D-02
	-2.80653D 03	1.76353D 01	-7.08652D 04	1.86072D 03	-1.63494D 03	1.40183D 02

Figure 2-10. Sample Case Output, Time History Print (Sheet 2 of 11)

	5.81588D 00	1.73609D 01	3.21743D 02			
	2.89349D 01	6.69741D 01	-1.54862D 02	1.00047D 01	1.81723D 01	-1.56725D 01
NODE 4	-1.16010D 01	2.00062D 01	-2.17781D 01			
	8.70249D 00	1.42579D 01	2.71573D 02			
	5.81588D 00	1.48541D 01	2.71618D 02			
	2.92187D 01	4.68407D 01	2.79953D 01	1.01425D 01	1.57301D 01	-5.27597D 01
NODE 5	-3.60106D 00	1.30068D 01	-2.18786D 01			
	9.44573D 00	1.51339D 01	2.69721D 02			
	6.57883D 00	1.57260D 01	2.69772D 02			
	3.54653D 01	5.39814D 01	-4.14814D 01	1.09139D 01	1.66148D 01	-5.76690D 01

MASS IMPULSES(G-SEC)-BASED ON FILTERED ACCELS

	XIMPULSE	YIMPULSE	ZIMPULSE
MASS 1	-1.55593D-03	5.75553D-05	7.26879D-04
MASS 2	-1.51413D-03	6.93273D-05	-1.01684D-02
MASS 3	-1.56153D-03	5.61290D-04	-2.87819D-02
MASS 4	-1.56313D-03	9.16112D-05	-5.64270D-02
MASS 5	-1.69217D-03	1.36235D-03	-8.33046D-02
MASS 6	-1.49205D-03	1.81941D-04	-1.04259D-01
MASS 7	-3.21128D-04	1.95904D-04	1.51149D-03
MASS 8	-3.06105D-04	2.30407D-04	1.49883D-03
MASS 9	-4.62389D-04	1.00738D-03	4.48107D-03
MASS 10	-5.69983D-05	3.01850D-04	-1.21572D-02
MASS 11	-3.06040D-04	3.22758D-03	-4.37792D-02
MASS 12	-6.10886D-05	8.63626D-04	-4.60687D-02
MASS 13	-1.01864D-05	-1.12373D-08	7.46140D-04
NODE 1	-2.62280D-05	-1.12373D-08	1.97062D-03
MASS 14	-1.01579D-05	-3.57768D-10	7.80810D-04
MASS 15	-1.01575D-05	-6.65743D-11	7.75370D-04
MASS 16	6.01765D-03	-8.10250D-03	-4.76635D-02
NODE 1	6.49487D-03	-9.19311D-03	-2.35943D-02
NODE 2	6.55912D-03	-7.54197D-03	-8.42611D-02
NODE 3	5.42455D-03	-9.16555D-03	9.84681D-03
NODE 4	5.48879D-03	-7.51441D-03	-5.08200D-02
NODE 5	6.00161D-03	-8.10250D-03	-4.64391D-02
MASS 17	-1.55593D-03	-5.75553D-05	7.26879D-04
MASS 18	-1.51413D-03	-6.93273D-05	-1.01684D-02
MASS 19	-1.56153D-03	-5.61290D-04	-2.87819D-02
MASS 20	-1.56313D-03	-9.16112D-05	-5.64270D-02
MASS 21	-1.69217D-03	-1.36235D-03	-8.33046D-02
MASS 22	-1.49205D-03	-1.81941D-04	-1.04259D-01
MASS 23	-3.21128D-04	-1.95904D-04	1.51149D-03
MASS 24	-3.06105D-04	-2.30407D-04	1.49883D-03
MASS 25	-4.62389D-04	-1.00738D-03	4.48107D-03
MASS 26	-5.69983D-05	-3.01850D-04	-1.21572D-02
MASS 27	-3.06040D-04	-3.22758D-03	-4.37792D-02
MASS 28	-6.10886D-05	-8.63626D-04	-4.60687D-02
MASS 29	-1.01864D-05	1.12373D-08	7.46140D-04
NODE 1	-2.62280D-05	1.12373D-08	1.97062D-03
MASS 30	-1.01579D-05	3.57768D-10	7.80810D-04
MASS 31	-1.01575D-05	6.65743D-11	7.75370D-04
MASS 32	6.01765D-03	8.10250D-03	-4.76635D-02
NODE 1	6.49487D-03	9.19311D-03	-2.35943D-02
NODE 2	6.55912D-03	7.54197D-03	-8.42611D-02
NODE 3	5.42455D-03	9.16555D-03	9.84681D-03
NODE 4	5.48879D-03	7.51441D-03	-5.08200D-02

Figure 2-10. Sample Case Output, Time History Print (Sheet 3 of 11)

NODE 5 6.001610-03 8.102500-03 -4.643910-02
BEAM FORCES

STRAIN FORCES

I	J	M	N	FX	FY	FZ	MX	MYI	MYJ	MZI	MZJ
1	2	0	0	1.5009D 01	-3.0043D-01	-6.2398D 02	1.7419D 02	-6.2504D 01	-3.0573D 03	1.5532D 00	-5.1059D-02
2	3	0	0	8.8593D 01	-1.8339D 00	6.0275D 02	2.6708D 02	4.0067D 03	2.6235D 03	1.0699D 01	9.4735D 00
3	4	0	0	8.0775D 01	2.8949D 00	-1.2534D 03	2.1273D 03	-1.2326D 04	-2.7141D 03	-1.6745D 01	-1.7994D 01
4	5	0	0	1.8568D 02	-6.0690D 00	2.4552D 02	1.0108D 02	-2.1072D 03	4.8079D 03	3.2393D 01	3.4367D 01
5	6	0	0	-3.4097D 01	1.0292D 01	-9.0914D 02	9.1203D 02	-6.3800D 03	1.6060D 01	-5.4555D 01	-1.7488D 01
7	8	0	0	6.7195D 00	-2.2099D 00	-1.4167D 01	5.2191D 00	-2.3924D 01	-4.6909D 01	6.3625D 00	4.6870D 00
8	9	0	0	2.8875D 01	-2.3977D 00	8.6803D 01	2.9125D 00	4.7080D 02	4.8402D 02	1.3509D 01	1.2866D 01
9	10	0	0	-2.6529D 01	2.3598D 00	-3.2042D 02	2.9167D 01	-1.9793D 03	-1.8656D 03	-1.3546D 01	-1.4771D 01
10	11	0	0	4.0463D 01	-8.4145D 00	-8.3011D 02	8.0415D 01	-4.6195D 03	-4.5117D 03	4.7803D 01	4.4756D 01
11	12	0	0	-3.6344D 01	4.3107D 01	7.6076D 01	2.3440D 02	7.5565D 01	4.5688D 02	-1.4519D 02	-1.5655D 02
1	17	0	0	-2.6883D 00	-5.3309D-12	-2.9674D-11	-4.2986D-12	-2.0954D 02	2.0954D 02	1.3392D-02	-1.3392D-02
2	18	0	0	-6.5012D 00	1.7573D-14	5.4278D-11	4.1815D-11	-4.0980D 01	4.0980D 01	-2.8532D-02	2.8532D-02
3	19	0	0	-2.1858D 02	-1.1401D-12	3.1283D-10	1.0208D-11	5.2712D 02	-5.2712D 02	-9.0688D-02	9.0688D-02
4	20	0	0	-1.0178D 01	-1.2129D-12	1.3105D-10	8.5492D-11	5.4603D 03	-5.4603D 03	-2.6707D-02	2.6707D-02
5	21	0	0	-6.3795D 02	3.2265D-13	3.4081D-10	2.4573D-11	5.6744D 03	-5.6744D 03	1.1755D-01	-1.1755D-01
6	22	0	0	-6.3583D 01	1.5765D-13	1.7040D-10	5.5412D-11	6.8991D 03	-6.8991D 03	1.6801D 00	-1.6801D 00
1	7	0	0	-2.2735D 00	1.7695D-01	2.1587D 01	-4.0117D 02	1.7832D 02	1.2389D 02	-1.2643D 00	-1.2129D 00
2	8	0	0	-4.1371D 00	2.1510D-01	0.0	-3.6665D 02	0.0	0.0	-1.5224D 00	-1.4891D 00
3	9	0	0	-3.3716D 01	2.6517D-01	9.1484D 02	-3.2342D 02	6.3220D 03	6.4855D 03	-1.8784D 00	-1.8339D 00
4	10	0	0	3.4696D-01	3.8710D-01	6.9454D 02	-5.7434D 02	3.2523D 03	6.4712D 03	-2.6701D 00	-2.7493D 00
5	11	0	0	-2.0839D 02	4.1539D-01	1.0791D 03	-7.3099D 02	7.0252D 03	8.0822D 03	-2.7253D 00	-3.0898D 00
6	12	0	0	-4.7115D 01	3.2929D-01	8.0393D 02	-7.6203D 02	7.3529D 03	3.9021D 03	-1.2608D 00	-3.3492D 00
3	16	0	1	-2.1566D 02	-1.9316D 02	1.5475D 02	1.1554D 01	9.8473D 02	1.2284D 03	6.1450D 02	2.1481D 03
5	16	0	2	-1.1755D 03	-4.5604D 02	2.6683D 02	1.2196D 01	2.0558D 03	1.7559D 03	3.0696D 03	3.4424D 03
9	16	0	3	-7.2402D 02	-1.6170D 02	9.3363D 01	1.3167D 01	3.6386D 02	9.7080D 02	3.2017D 02	1.9914D 03
11	16	0	4	1.1172D 03	-2.8339D 02	1.1062D 02	2.7116D 00	5.3049D 02	1.0518D 03	1.4994D 03	2.5544D 03
13	14	0	0	1.6654D 00	-3.7817D-06	-7.8971D-06	6.3591D-15	-5.9675D-05	-5.9492D-05	2.8576D-05	2.8490D-05
13	15	0	0	5.9521D-02	-2.3958D-07	-4.9494D-07	3.1879D-16	-3.7228D-06	-3.7458D-06	1.7989D-06	1.8163D-06
5	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	16	0	0	-2.3144D 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	16	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	18	0	0	1.5009D 01	3.0043D-01	-6.2398D 02	-1.7419D 02	-6.2504D 01	-3.0573D 03	-1.5532D 00	5.1059D-02
18	19	0	0	8.8593D 01	1.8339D 00	6.0275D 02	-2.6708D 02	4.0067D 03	2.6235D 03	-1.0699D 01	-9.4735D 00
19	20	0	0	8.0775D 01	-2.8949D 00	-1.2534D 03	-2.1273D 03	-1.2326D 04	-2.7141D 03	1.6745D 01	1.7994D 01
20	21	0	0	1.8568D 02	6.0690D 00	2.4552D 02	-1.0108D 02	-2.1072D 03	4.8079D 03	-3.2393D 01	-3.4367D 01
21	22	0	0	-3.4097D 01	-1.0292D 01	-9.0914D 02	-9.1203D 02	-6.3800D 03	1.6060D 01	5.4555D 01	1.7488D 01
23	24	0	0	6.7195D 00	2.2099D 00	-1.4167D 01	-5.2191D 00	-2.3924D 01	-4.6909D 01	-6.3625D 00	-4.6870D 00
24	25	0	0	2.8875D 01	2.3977D 00	8.6803D 01	-2.9125D 00	4.7080D 02	4.8402D 02	-1.3509D 01	-1.2866D 01
25	26	0	0	-2.6529D 01	-2.3598D 00	-3.2042D 02	-2.9167D 01	-1.9793D 03	-1.8656D 03	1.3546D 01	1.4771D 01
26	27	0	0	4.0463D 01	8.4145D 00	-8.3011D 02	-8.0415D 01	-4.6195D 03	-4.5117D 03	-4.7803D 01	-4.4756D 01
27	28	0	0	-3.6344D 01	-4.3107D 01	7.6076D 01	-2.3440D 02	7.5565D 01	4.5688D 02	1.4519D 02	1.5655D 02
17	23	0	0	-2.2735D 00	-1.7695D-01	2.1587D 01	4.0117D 02	1.7832D 02	1.2389D 02	1.2643D 00	1.2129D 00
18	24	0	0	-4.1371D 00	-2.1510D-01	0.0	3.6665D 02	0.0	0.0	1.5224D 00	1.4891D 00
19	25	0	0	-3.3716D 01	-2.6517D-01	9.1484D 02	3.2342D 02	6.3220D 03	6.4855D 03	1.8784D 00	1.8339D 00
20	26	0	0	3.4696D-01	-3.8710D-01	6.9454D 02	5.7434D 02	3.2523D 03	6.4712D 03	2.6701D 00	2.7493D 00
21	27	0	0	-2.0839D 02	-4.1538D-01	1.0791D 03	7.3099D 02	7.0252D 03	8.0822D 03	2.7253D 00	3.0898D 00
22	28	0	0	-4.7115D 01	-3.2929D-01	8.0393D 02	7.6203D 02	7.3529D 03	3.9021D 03	1.2608D 00	3.3492D 00
19	32	0	1	-2.1566D 02	1.9316D 02	1.5475D 02	-1.1554D 01	9.8473D 02	1.2284D 03	-6.1450D 02	-2.1481D 03
21	32	0	2	-1.1755D 03	4.5604D 02	2.6683D 02	-1.2196D 01	2.0558D 03	1.7559D 03	-3.0696D 03	-3.4424D 03
25	32	0	3	-7.2402D 02	1.6170D 02	9.3363D 01	-1.3167D 01	3.6386D 02	9.7080D 02	-3.2017D 02	-1.9914D 03
27	32	0	4	1.1172D 03	2.8339D 02	1.1062D 02	-2.7116D 00	5.3049D 02	1.0518D 03	-1.4994D 03	-2.5544D 03
29	30	0	0	1.6654D 00	3.7817D-06	-7.8971D-06	-6.3591D-15	-5.9675D-05	-5.9492D-05	-2.8576D-05	-2.8490D-05
29	31	0	0	5.9521D-02	2.3958D-07	-4.9494D-07	-3.1879D-16	-3.7228D-06	-3.7458D-06	-1.7989D-06	-1.8163D-06

Figure 2-10. Sample Case Output, Time History Print (Sheet 4 of 11)

21	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	32	0	0	-2.3144D 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	32	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TOTAL FORCES (STRAIN+DAMPING)

I	J	M	N	FX	FY	FZ	MX	MYI	MYJ	MZI	MZJ
1	2	0	0	1.4845D 01	-2.2432D-01	-6.2223D 02	1.5802D 02	-4.9986D 01	-3.0611D 03	1.3850D 00	-2.6338D-01
2	3	0	0	8.9007D 01	-2.0218D 00	6.3642D 02	3.1183D 02	4.1768D 03	2.8237D 03	1.1906D 01	1.0334D 01
3	4	0	0	7.8101D 01	3.4544D 00	-1.2385D 03	2.0939D 03	-1.2019D 04	-2.8427D 03	-2.0287D 01	-2.1166D 01
4	5	0	0	1.8452D 02	-6.6109D 00	2.4908D 02	5.6775D 01	-2.1547D 03	4.8945D 03	3.5184D 01	3.7537D 01
5	6	0	0	-3.4482D 01	9.8026D 00	-9.1100D 02	9.2508D 02	-6.4066D 03	2.9603D 01	-5.4236D 01	-1.4379D 01
7	8	0	0	6.8091D 00	-2.1818D 00	-4.9670D 00	8.6523D 00	1.0384D 00	-2.5873D 01	6.3273D 00	4.5814D 00
8	9	0	0	2.9679D 01	-3.3416D 00	9.0975D 01	1.2326D 01	4.9151D 02	5.0921D 02	1.8823D 01	1.7935D 01
9	10	0	0	-2.7864D 01	3.5048D 00	-3.9257D 02	5.5064D 01	-2.4287D 03	-2.2819D 03	-2.0183D 01	-2.1873D 01
10	11	0	0	4.2600D 01	-1.0577D 01	-9.2957D 02	1.2365D 02	-5.1699D 03	-5.0554D 03	5.9862D 01	5.6479D 01
11	12	0	0	-3.6658D 01	4.7190D 01	7.0537D 01	2.8651D 02	5.0648D 01	4.4302D 02	-1.5977D 02	-1.7055D 02
1	17	0	0	-2.8176D 00	1.4347D-11	-2.9515D-11	-4.7281D-12	-2.0035D 02	2.0035D 02	8.4121D-03	-8.4121D-03
2	18	0	0	-6.7501D 00	-1.2384D-11	6.3083D-11	5.8130D-11	-4.2465D 01	4.2465D 01	-6.7519D-02	6.7519D-02
3	19	0	0	-2.2794D 02	8.2988D-13	3.1294D-10	1.4753D-11	6.1543D 02	-6.1543D 02	-2.4835D-01	2.4835D-01
4	20	0	0	-1.0837D 01	-1.7055D-12	1.4253D-10	6.6467D-11	5.4737D 03	-5.4737D 03	-8.1365D-02	8.1365D-02
5	21	0	0	-6.4648D 02	-9.7632D-13	3.2987D-10	1.3244D-11	5.6387D 03	-5.6387D 03	1.4513D-01	-1.4513D-01
6	22	0	0	-6.4349D 01	-5.5295D-12	1.6098D-10	7.0215D-11	6.8865D 03	-6.8865D 03	2.3344D 00	-2.3344D 00
1	7	0	0	-2.4390D 00	2.9259D-01	3.6750D 01	-4.1903D 02	2.7995D 02	2.3453D 02	-2.0791D 00	-2.0171D 00
2	8	0	0	-4.3159D 00	4.6424D-01	0.0	-4.0890D 02	0.0	0.0	-3.2842D 00	-3.2150D 00
3	9	0	0	-3.8117D 01	7.2837D-01	1.0781D 03	-5.2794D 02	7.4396D 03	7.6534D 03	-5.1765D 00	-5.0204D 00
4	10	0	0	-2.4313D-01	7.0684D-01	7.0795D 02	-5.3867D 02	3.2523D 03	6.6589D 03	-4.8544D 00	-5.0412D 00
5	11	0	0	-2.1862D 02	5.7142D-01	1.0727D 03	-7.3040D 02	7.0244D 03	7.9933D 03	-3.7095D 00	-4.2901D 00
6	12	0	0	-4.8273D 01	2.3297D-01	8.0534D 02	-7.6723D 02	7.3725D 03	3.9021D 03	-2.2246D-01	-3.0392D 00
3	16	0	1	-2.6888D 02	-2.1008D 02	1.8283D 02	1.2937D 01	1.2055D 03	1.4092D 03	6.6424D 02	2.3403D 03
5	16	0	2	-1.0643D 03	-4.5584D 02	2.7032D 02	1.4607D 01	2.0670D 03	1.7945D 03	3.0020D 03	3.5070D 03
9	16	0	3	-6.6398D 02	-1.6838D 02	1.0159D 02	1.6312D 01	3.7326D 02	1.0790D 03	2.5512D 02	2.1519D 03
11	16	0	4	1.1063D 03	-3.0618D 02	1.2187D 02	3.6187D 00	5.7939D 02	1.1640D 03	1.6087D 03	2.7712D 03
13	14	0	0	-3.2094D-01	5.8109D-05	-1.4615D-04	1.6820D-13	-1.1045D-03	-1.1009D-03	-4.3781D-04	-4.3904D-04
13	15	0	0	-1.9603D-01	1.0935D-05	-2.7194D-05	4.4565D-14	-2.0449D-04	-2.0586D-04	-8.3248D-05	-8.2518D-05
5	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	16	0	0	-2.3144D 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	16	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	18	0	0	1.4845D 01	2.2432D-01	-6.2223D 02	-1.5802D 02	-4.9986D 01	-3.0611D 03	-1.3850D 00	2.6338D-01
18	19	0	0	8.9007D 01	2.0218D 00	6.3642D 02	-3.1183D 02	4.1768D 03	2.8237D 03	-1.1906D 01	-1.0334D 01
19	20	0	0	7.8101D 01	-3.4544D 00	-1.2385D 03	-2.0939D 03	-1.2019D 04	-2.8427D 03	2.0287D 01	2.1166D 01
20	21	0	0	1.8452D 02	6.6109D 00	2.4908D 02	-5.6775D 01	-2.1547D 03	4.8945D 03	-3.5184D 01	-3.7537D 01
21	22	0	0	-3.4482D 01	-9.8026D 00	-9.1100D 02	-9.2508D 02	-6.4066D 03	2.9603D 01	5.4236D 01	1.4379D 01
23	24	0	0	6.8091D 00	2.1818D 00	-4.9670D 00	-8.6523D 00	1.0384D 00	-2.5873D 01	-6.3273D 00	-4.5814D 00
24	25	0	0	2.9679D 01	3.3416D 00	9.0975D 01	-1.2326D 01	4.9151D 02	5.0921D 02	-1.8823D 01	-1.7935D 01
25	26	0	0	-2.7864D 01	-3.5048D 00	-3.9257D 02	-5.5064D 01	-2.4287D 03	-2.2819D 03	2.0183D 01	2.1873D 01
26	27	0	0	4.2600D 01	1.0577D 01	-9.2957D 02	-1.2365D 02	-5.1699D 03	-5.0554D 03	-5.9862D 01	-5.6479D 01
27	28	0	0	-3.6658D 01	-4.7190D 01	7.0537D 01	-2.8651D 02	5.0648D 01	4.4302D 02	1.5977D 02	1.7055D 02
17	23	0	0	-2.4390D 00	-2.9259D-01	3.6750D 01	4.1903D 02	2.7995D 02	2.3453D 02	2.0791D 00	2.0171D 00
18	24	0	0	-4.3159D 00	-4.6424D-01	0.0	4.0890D 02	0.0	0.0	3.2842D 00	3.2150D 00
19	25	0	0	-3.8117D 01	-7.2837D-01	1.0781D 03	5.2794D 02	7.4396D 03	7.6534D 03	5.1765D 00	5.0204D 00
20	26	0	0	-2.4313D-01	-7.0684D-01	7.0795D 02	5.3867D 02	3.2523D 03	6.6589D 03	4.8544D 00	5.0412D 00
21	27	0	0	-2.1862D 02	-5.7142D-01	1.0727D 03	7.3040D 02	7.0244D 03	7.9933D 03	3.7095D 00	4.2901D 00
22	28	0	0	-4.8273D 01	-2.3297D-01	8.0534D 02	7.6723D 02	7.3725D 03	3.9021D 03	2.2246D-01	3.0392D 00
19	32	0	1	-2.6888D 02	2.1008D 02	1.8283D 02	-1.2937D 01	1.2055D 03	1.4092D 03	-6.6424D 02	-2.3403D 03
21	32	0	2	-1.0643D 03	4.5584D 02	2.7032D 02	-1.4607D 01	2.0670D 03	1.7945D 03	-3.0020D 03	-3.5070D 03
25	32	0	3	-6.6398D 02	1.6838D 02	1.0159D 02	-1.6312D 01	3.7326D 02	1.0790D 03	-2.5512D 02	-2.1519D 03
27	32	0	4	1.1063D 03	3.0618D 02	1.2187D 02	-3.6187D 00	5.7939D 02	1.1640D 03	-1.6087D 03	-2.7712D 03

Figure 2-10. Sample Case Output, Time History Print (Sheet 5 of 11)

29	30	0	0	-3.2094D-01	-5.8109D-05	-1.4615D-04	-1.6820D-13	-1.1045D-03	-1.1009D-03	4.3781D-04	4.3904D-04
29	31	0	0	-1.9603D-01	-1.0985D-05	-2.7194D-05	-4.4565D-14	-2.0449D-04	-2.0586D-04	8.3248D-05	8.2518D-05
21	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	32	0	0	-2.3144D 01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	32	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

BEAM RELATIVE DEFLECTIONS AND ROTATIONS AND BEAM EULER ANGLES (INCHES AND DEGREES)

BEAM				DEFLECTIONS (J-I)			ROTATIONS (J-I)			ROTATIONS (J+I)		EULER ANGLES	
I	J	M	N	X	Y	Z	PHI	THETA	PSI	THETA	PSI	THETA	PSI
1	2	0	0	1.1609D-05	-4.9248D-06	-1.4814D-04	2.9404D-03	-9.7684D-03	-3.6161D-04	1.9635D-01	-5.4724D-05	-0.6	180.0
2	3	0	0	1.5075D-04	-3.2009D-04	1.5223D-03	9.9185D-03	-9.9264D-03	-6.0772D-04	1.7665D-01	-1.0327D-03	-0.7	180.0
3	4	0	0	1.4994D-04	6.5599D-04	-4.1100D-03	8.6181D-02	7.5249D-02	-6.7545D-04	2.4197D-01	-2.3989D-03	-0.6	-180.0
4	5	0	0	3.1595D-04	-1.0593D-03	6.2024D-04	3.7536D-03	4.9623D-02	9.7923D-04	3.6686D-01	-2.0322D-03	-0.6	180.0
5	6	0	0	-3.6921D-05	4.6295D-04	-5.9207D-04	2.1554D-02	2.9208D-02	1.1697D-02	4.4567D-01	1.0721D-02	-0.5	-180.0
7	8	0	0	2.4998D-05	-5.1384D-05	-4.1123D-05	9.7234D-04	-9.1746D-04	-5.3578D-04	-5.5365D-04	6.7842D-04	-0.8	180.0
8	9	0	0	2.3633D-04	-5.9363D-04	2.6830D-03	1.1937D-03	1.1605D-03	-4.5291D-04	-3.1060D-04	-3.1027D-04	-0.8	180.0
9	10	0	0	-2.3686D-04	7.5851D-04	-1.2858D-02	1.3041D-02	1.0903D-02	-9.3957D-04	1.1752D-02	-1.6993D-03	-0.7	-180.0
10	11	0	0	3.3117D-04	-2.0833D-03	-2.5658D-02	3.2960D-02	9.4699D-03	-2.1438D-03	3.2129D-02	-4.7583D-03	-0.6	180.0
11	12	0	0	-1.8929D-04	2.7503D-03	6.0584D-04	6.1136D-02	2.1304D-02	-5.0832D-03	6.2877D-02	-1.2099D-02	-0.7	-180.0
1	17	0	0	-1.0621D-05	-1.7195D-14	-2.1716D-16	-3.9340D-16	7.3216D-03	-2.0625D-04	2.0604D-15	1.9813D-13	-0.0	90.0
2	18	0	0	-2.5684D-05	5.6749D-17	3.9720D-16	3.8267D-15	1.4319D-03	4.3943D-04	7.9692D-15	3.3384D-14	0.0	90.0
3	19	0	0	-8.6353D-04	-3.6775D-15	2.2893D-15	9.3418D-16	-1.8419D-02	1.3967D-03	1.3390D-14	1.3901D-14	0.0	90.0
4	20	0	0	-4.0210D-05	-3.9122D-15	9.5906D-16	7.8238D-15	-1.9079D-01	4.1132D-04	2.8496D-15	2.0510D-14	-0.0	90.0
5	21	0	0	-2.5204D-03	1.0413D-15	2.4940D-15	2.2498D-15	-1.9827D-01	-1.8104D-03	2.5691D-15	2.7134D-15	0.0	90.0
6	22	0	0	-2.5120D-04	5.0877D-16	1.2470D-15	5.0710D-15	-2.4107D-01	-2.5875D-02	-7.1665D-15	-4.9261D-15	0.0	90.0
1	7	0	0	-1.3878D-05	9.4147D-04	6.0434D-04	-1.0288D-01	-2.6729D-03	4.8012D-04	4.6404D-03	7.0722D-04	-0.0	-90.0
2	8	0	0	-2.5254D-05	1.1445D-03	8.8227D-03	-9.4024D-02	-7.0766D-04	3.1123D-04	7.1660D-04	-1.6842D-04	-0.0	-90.0
3	9	0	0	-2.0581D-04	1.4109D-03	2.5611D-02	-8.2936D-02	8.0176D-03	4.1616D-04	-1.0408D-02	-1.1471D-03	-0.1	-90.0
4	10	0	0	2.1179D-06	2.0596D-03	2.8839D-02	-1.4728D-01	8.1147D-02	-7.3925D-04	-1.0965D-01	-1.5501D-03	-0.2	-90.0
5	11	0	0	-1.2720D-03	2.2100D-03	3.0210D-02	-1.8745D-01	5.1906D-02	-3.4006D-03	-1.4638D-01	-2.3548D-03	-0.2	-90.0
6	12	0	0	-2.8760D-04	1.7521D-03	4.4689D-02	-1.9541D-01	1.2122D-02	-1.9484D-02	-2.2901D-01	5.1557D-03	-0.3	-90.0
3	16	0	1	-1.6335D-03	-8.7187D-03	2.0953D-02	3.4600D-03	5.5535D-02	1.1637D-01	2.2156D-01	1.3921D-01	89.3	-177.3
5	16	0	2	-8.9031D-03	-2.0539D-02	3.6076D-02	3.6522D-03	-6.9160D-02	2.7561D-02	3.4695D-01	2.2739D-01	89.3	-177.6
9	16	0	3	-5.4838D-03	-7.2914D-03	1.2634D-02	3.9430D-03	1.3804D-01	1.2673D-01	1.3877D-01	1.2915D-01	89.3	-177.2
11	16	0	4	8.4615D-03	-1.2797D-02	1.4982D-02	8.1202D-04	1.1878D-01	8.0134D-02	1.5831D-01	1.7533D-01	89.3	-177.1
13	14	0	0	1.1967D-04	-1.3751D-08	-2.8715D-08	9.1634D-17	1.0111D-09	-4.6907D-10	6.5502D-09	-4.5229D-09	89.2	180.0
13	15	0	0	1.2480D-04	-1.4292D-08	-2.9526D-08	9.5702D-17	-2.0626D-09	1.5607D-09	3.4765D-09	-2.4932D-09	89.2	180.0
5	13	0	0	-7.7644D-02	-1.2005D-02	-6.4716D-03	-2.7997D-02	2.2082D-01	-6.0389D-02	-2.2082D-01	6.0389D-02	64.5	-42.2
11	13	0	0	-3.6028D-02	7.0391D-03	1.9217D-02	1.8425D-02	-1.6338D-02	4.5444D-02	1.6338D-02	-4.5444D-02	64.5	42.2
13	16	0	0	-4.3390D-02	-1.4631D-02	-1.4913D-02	-4.3018D-03	-1.4423D-01	1.2187D-01	-1.4423D-01	1.2187D-01	-89.2	-3.9
13	16	1	5	-4.3390D-02	-1.4631D-02	-1.4913D-02	-4.3018D-03	-1.4423D-01	1.2187D-01	-1.4423D-01	1.2187D-01	-89.2	-3.9
17	18	0	0	1.1609D-05	4.9248D-06	-1.4814D-04	-2.9404D-03	-9.7684D-03	3.6161D-04	1.9635D-01	5.4724D-05	-0.6	-180.0
18	19	0	0	1.5075D-04	3.2009D-04	1.5223D-03	-9.9185D-03	-9.9264D-03	6.0772D-04	1.7665D-01	1.0327D-03	-0.7	-180.0
19	20	0	0	1.4994D-04	-6.5599D-04	-4.1100D-03	-8.6181D-02	7.5249D-02	6.7545D-04	2.4197D-01	2.3989D-03	-0.6	180.0
20	21	0	0	3.1595D-04	1.0593D-03	6.2024D-04	-3.7536D-03	4.9623D-02	-9.7923D-04	3.6686D-01	2.0322D-03	-0.6	-180.0
21	22	0	0	-3.6921D-05	-4.6295D-04	-5.9207D-04	-2.1554D-02	2.9208D-02	-1.1697D-02	4.4567D-01	-1.0721D-02	-0.5	180.0
23	24	0	0	2.4998D-05	5.1384D-05	-4.1123D-05	-9.7234D-04	-9.1746D-04	5.3578D-04	-5.5365D-04	-6.7842D-04	-0.8	-180.0
24	25	0	0	2.3633D-04	5.9363D-04	2.6830D-03	-1.1937D-03	1.1605D-03	4.5291D-04	-3.1060D-04	3.1027D-04	-0.8	-180.0
25	26	0	0	-2.3686D-04	-7.5851D-04	-1.2858D-02	-1.3041D-02	1.0903D-02	9.3957D-04	1.1752D-02	1.6993D-03	-0.7	180.0
26	27	0	0	3.3117D-04	2.0833D-03	-2.5658D-02	-3.2960D-02	9.4699D-03	2.1438D-03	3.2129D-02	4.7583D-03	-0.6	-180.0
27	28	0	0	-1.8929D-04	-2.7503D-03	6.0584D-04	-6.1136D-02	2.1304D-02	5.0832D-03	6.2877D-02	1.2099D-02	-0.7	180.0
17	23	0	0	-1.3878D-05	-9.4147D-04	6.0434D-04	1.0288D-01	-2.6729D-03	-4.8012D-04	4.6404D-03	-7.0722D-04	-0.0	90.0
18	24	0	0	-2.5254D-05	-1.1445D-03	8.8227D-03	9.4024D-02	-7.0766D-04	-3.1123D-04	7.1660D-04	1.6842D-04	-0.0	90.0
19	25	0	0	-2.0581D-04	-1.4109D-03	2.5611D-02	8.2936D-02	8.0176D-03	-4.1616D-04	-1.0408D-02	1.1471D-03	-0.1	90.0
20	26	0	0	2.1179D-06	-2.0596D-03	2.8839D-02	1.4728D-01	8.1147D-02	7.3925D-04	-1.0965D-01	1.5501D-03	-0.2	90.0
21	27	0	0	-1.2720D-03	-2.2100D-03	3.0210D-02	1.8745D-01	5.1906D-02	3.4006D-03	-1.4638D-01	2.3548D-03	-0.2	90.0

Figure 2-10. Sample Case Output, Time History Print (Sheet 6 of 11)

22	28	0	0	-2.8760D-04	-1.7521D-03	4.4689D-02	1.9541D-01	1.2122D-02	1.9489D-02	-2.2901D-01	-5.1557D-03	-0.3	90.0
19	32	0	1	-1.6335D-03	8.7187D-03	2.0953D-02	-3.4600D-03	5.5535D-02	-1.1637D-01	2.2156D-01	-1.3921D-01	89.3	177.3
21	32	0	2	-8.9031D-03	2.0539D-02	3.6076D-02	-3.6522D-03	-6.9160D-02	-2.7561D-02	3.4695D-01	-2.2730D-01	89.3	177.6
25	32	0	3	-5.4838D-03	7.2914D-03	1.2634D-02	-3.9430D-03	1.3804D-01	-1.2673D-01	1.3877D-01	-1.2915D-01	89.3	177.2
27	32	0	4	8.4615D-03	1.2797D-02	1.4982D-02	-8.1202D-04	1.1878D-01	-8.0134D-02	1.5831D-01	-1.7539D-01	89.3	177.1
29	30	0	0	1.1967D-04	1.3751D-08	-2.8715D-08	-9.1634D-17	1.0111D-09	4.6907D-10	6.5502D-09	4.5229D-09	89.2	-180.0
29	31	0	0	1.2480D-04	1.4292D-08	-2.9526D-08	-9.5702D-17	-2.0626D-09	-1.5607D-09	3.4765D-09	2.4932D-09	89.2	-180.0
21	29	0	0	-7.7644D-02	1.2005D-02	-6.4716D-03	2.7997D-02	2.2082D-01	6.0389D-02	-2.2082D-01	-6.0389D-02	64.5	42.2
27	29	0	0	-3.6028D-02	-7.0391D-03	1.9217D-02	-1.8425D-02	-1.6338D-02	-4.5444D-02	1.6338D-02	4.5444D-02	64.5	-42.2
29	32	0	0	-4.3390D-02	1.4631D-02	-1.4913D-02	4.3018D-03	-1.4423D-01	-1.2187D-01	-1.4423D-01	-1.2187D-01	-89.2	3.9
29	32	1	5	-4.3390D-02	1.4631D-02	-1.4913D-02	4.3018D-03	-1.4423D-01	-1.2187D-01	-1.4423D-01	-1.2187D-01	-89.2	3.9

EXTERNAL SPRINGS

						GROUND CONTACT POINT LOADS IN GROUND OR SLOPE AXES			GROUND CONTACT POINT LOADS IN MASS AXES		
MASS I	SPRING K	M	SPRING COMPRESSION	GROUND DEFLECTION	SPRING COMPRESSION LOAD	X(+ AFT OR DOWN SLOPE)	Y(+ LEFT)	Z(+ UP OR NORMAL TO SLOPE)	X (+ FORWARD)	Y (+ RIGHT)	Z (+ DOWN)
2	3	0	1.14536D-01	0.0	2.29000D 03	0.0	0.0	2.289850 03	2.624660 01	-2.887560-02	-2.289700 03
3	3	0	2.43033D-01	0.0	2.65000D 03	0.0	0.0	2.649820 03	3.082940 01	4.318140-01	-2.649640 03
4	3	0	3.70836D-01	0.0	2.65000D 03	0.0	0.0	2.649850 03	2.738880 01	4.414240 00	-2.649710 03
5	3	0	4.80444D-01	0.0	2.41000D 03	0.0	0.0	2.409890 03	2.280530 01	4.164710 00	-2.409780 03
6	3	0	5.44306D-01	0.0	1.76000D 03	0.0	0.0	1.759930 03	1.575260 01	3.701920 00	-1.759850 03
8	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	3	0	1.14536D-01	0.0	2.29000D 03	0.0	0.0	2.289850 03	2.624660 01	2.887560-02	-2.289700 03
19	3	0	2.43033D-01	0.0	2.65000D 03	0.0	0.0	2.649820 03	3.082940 01	-4.318140-01	-2.649640 03
20	3	0	3.70836D-01	0.0	2.65000D 03	0.0	0.0	2.649850 03	2.738880 01	-4.414240 00	-2.649710 03
21	3	0	4.80444D-01	0.0	2.41000D 03	0.0	0.0	2.409890 03	2.280530 01	-4.164710 00	-2.409780 03
22	3	0	5.44306D-01	0.0	1.76000D 03	0.0	0.0	1.759930 03	1.575260 01	-3.701920 00	-1.759850 03
24	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	3	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

DRI RESULTS: MASS NO. AND DRI VALUE

MASS	DRI
15	-8.17468D-04
31	-8.17468D-04

VEHICLE C.G. TRANSLATIONAL VELOCITIES, GROUND AXES, BASED ON SYSTEM LINEAR MOMENTUM

XDOT (+FWD)	YDOT (+RIGHT)	ZDOT (+DOWN)
-4.71167D-04	2.46708D-16	3.17143D 02

ENERGY DISTRIBUTION

TOTAL KINETIC POTENTIAL STRAIN DAMPING CRUSHING FRICTION

Figure 2-10. Sample Case Output, Time History Print (Sheet 7 of 11)

	ENERGY	ENERGY	ENERGY	ENERGY	ENERGY	ENERGY	ENERGY
	9.06241D 04	7.01393D 04	1.32810D 04	2.92191D 02	4.42938D 01	6.86727D 03	0.0
PERCENT OF TOTAL ENERGY		77.396	14.655	0.322	0.049	7.578	0.0

MASS	KINETIC ENERGY	PCT	POTENTIAL ENERGY	PCT	INTERNAL BEAM IJ	I	J	M	N	STRAIN ENERGY	PCT	DAMPING ENERGY	PCT	EXTERNAL SPRING I	K	M	CRUSHING ENERGY	PCT	FRICTION ENERGY	PCT
1	1.948D 02	0.3	1.247D 01	0.1	1	1	2	0	0	1.876D-01	0.1	4.373D-03	0.0	2	3	0	1.513D 02	2.2	0.0	0.0
2	5.678D 02	0.8	3.966D 01	0.3	2	2	3	0	0	5.914D-01	0.2	9.456D-02	0.2	3	3	0	5.154D 02	7.5	0.0	0.0
3	1.665D 03	2.4	1.335D 02	1.0	3	3	4	0	0	8.129D 00	2.8	2.324D 00	5.2	4	3	0	8.539D 02	12.4	0.0	0.0
4	6.524D 02	0.9	5.500D 01	0.4	4	4	5	0	0	2.021D 00	0.7	8.621D-01	1.9	5	3	0	1.041D 03	15.2	0.0	0.0
5	5.284D 02	0.8	4.241D 01	0.3	5	5	6	0	0	1.481D 00	0.5	2.035D-01	0.5	6	3	0	8.724D 02	12.7	0.0	0.0
6	1.950D 02	0.3	1.640D 01	0.1	6	7	8	0	0	6.617D-04	0.0	6.488D-04	0.0	8	3	0	0.0	0.0	0.0	0.0
7	4.471D 02	0.6	2.486D 01	0.2	7	8	9	0	0	1.220D-01	0.0	2.596D-02	0.1	9	3	0	0.0	0.0	0.0	0.0
8	1.439D 03	2.1	7.899D 01	0.6	8	9	10	0	0	2.099D 00	0.7	6.470D-01	1.5	10	3	0	0.0	0.0	0.0	0.0
9	3.520D 03	5.0	1.897D 02	1.4	9	10	11	0	0	1.079D 01	3.7	1.921D 00	4.3	11	3	0	0.0	0.0	0.0	0.0
10	1.759D 03	2.5	1.094D 02	0.8	10	11	12	0	0	2.714D-01	0.1	2.726D-01	0.6	12	3	0	0.0	0.0	0.0	0.0
11	1.065D 03	1.5	8.429D 01	0.6	11	1	17	0	0	1.396D-02	0.0	1.004D-03	0.0	18	3	0	1.513D 02	2.2	0.0	0.0
12	4.012D 02	0.6	3.241D 01	0.2	12	2	18	0	0	6.169D-04	0.0	7.056D-05	0.0	19	3	0	5.154D 02	7.5	0.0	0.0
13	1.032D 04	14.7	2.137D 03	16.1	13	3	19	0	0	1.826D-01	0.1	2.417D-02	0.1	20	3	0	8.539D 02	12.4	0.0	0.0
14	1.033D 04	14.7	3.237D 03	24.4	14	4	20	0	0	9.189D 00	3.1	3.720D-01	0.8	21	3	0	1.041D 03	15.2	0.0	0.0
15	0.0	0.0	0.0	0.0	15	5	21	0	0	1.074D 01	3.7	3.920D-01	0.9	22	3	0	8.724D 02	12.7	0.0	0.0
16	1.979D 03	2.8	4.485D 02	3.4	16	6	22	0	0	1.465D 01	5.0	2.634D-01	0.6	24	3	0	0.0	0.0	0.0	0.0
17	1.948D 02	0.3	1.247D 01	0.1	17	1	7	0	0	3.804D-01	0.1	6.278D-02	0.1	25	3	0	0.0	0.0	0.0	0.0
18	5.678D 02	0.8	3.966D 01	0.3	18	[illegible]	8	0	0	3.068D-01	0.1	8.051D-02	0.2	26	3	0	0.0	0.0	0.0	0.0
19	1.665D 03	2.4	1.335D 02	1.0	19	3	9	0	0	1.216D 01	4.2	3.394D 00	7.7	27	3	0	0.0	0.0	0.0	0.0
20	6.524D 02	0.9	5.500D 01	0.4	20	4	10	0	0	1.419D 01	4.9	1.131D 00	2.6	28	3	0	0.0	0.0	0.0	0.0
21	5.284D 02	0.8	4.241D 01	0.3	21	5	11	0	0	1.804D 01	6.2	1.413D 00	3.2							
22	1.950D 02	0.3	1.640D 01	0.1	22	6	12	0	0	2.542D 01	8.7	7.901D-01	1.8							
23	4.471D 02	0.6	2.486D 01	0.2	23	3	16	0	1	3.574D 00	1.2	1.296D 00	2.9							
24	1.439D 03	2.1	7.899D 01	0.6	24	5	16	0	2	1.584D 01	5.4	5.245D 00	11.8							
25	3.528D 03	5.0	1.887D 02	1.4	25	9	16	0	3	4.519D 00	1.5	9.287D-01	2.1							
26	1.759D 03	2.5	1.094D 02	0.8	26	11	16	0	4	8.079D 00	2.8	9.237D-01	2.1							
27	1.065D 03	1.5	8.429D 01	0.6	27	13	14	0	0	1.002D-04	0.0	-3.459D-05	-0.0							
28	4.012D 02	0.6	3.241D 01	0.2	28	13	15	0	0	0.0	0.0	0.0	0.0							
29	1.032D 04	14.7	2.137D 03	16.1	29	5	13	0	0	1.052D-08	0.0	0.0	0.0							
30	1.033D 04	14.7	3.237D 03	24.4	30	11	13	0	0	5.373D-08	0.0	0.0	0.0							
31	0.0	0.0	0.0	0.0	31	13	16	0	0	5.070D-01	0.2	0.0	0.0							
32	1.979D 03	2.8	4.485D 02	3.4	32	13	16	1	5	0.0	0.0	0.0	0.0							
					33	17	18	0	0	1.876D-01	0.1	4.373D-03	0.0							
					34	18	19	0	0	5.914D-01	0.2	9.456D-02	0.2							
					35	19	20	0	0	8.129D 00	2.8	2.324D 00	5.2							
					36	20	21	0	0	2.021D 00	0.7	8.621D-01	1.9							
					37	21	22	0	0	1.481D 00	0.5	2.035D-01	0.5							
					38	23	24	0	0	6.617D-04	0.0	6.488D-04	0.0							
					39	24	25	0	0	1.220D-01	0.0	2.596D-02	0.1							
					40	25	26	0	0	2.099D 00	0.7	6.470D-01	1.5							
					41	26	27	0	0	1.079D 01	3.7	1.921D 00	4.3							
					42	27	28	0	0	2.714D-01	0.1	2.726D-01	0.6							
					43	17	23	0	0	3.804D-01	0.1	6.278D-02	0.1							
					44	18	24	0	0	3.068D-01	0.1	8.051D-02	0.2							
					45	19	25	0	0	1.216D 01	4.2	3.394D 00	7.7							
					46	20	26	0	0	1.419D 01	4.9	1.131D 00	2.6							
					47	21	27	0	0	1.804D 01	6.2	1.413D 00	3.2							

Figure 2-10. Sample Case Output, Time History Print (Sheet 8 of 11)

48	22	28	0	0	2.542D 01	8.7	7.901D-01	1.8
49	19	32	0	1	3.574D 00	1.2	1.296D 00	2.9
50	21	32	0	2	1.584D 01	5.4	5.245D 00	11.8
51	25	32	0	3	4.519D 00	1.5	9.287D-01	2.1
52	27	32	0	4	8.079D 00	2.8	9.237D-01	2.1
53	29	30	0	0	1.002D-04	0.0	-3.459D-05	-0.0
54	29	31	0	0	0.0	0.0	0.0	0.0
55	21	29	0	0	1.052D-08	0.0	0.0	0.0
56	27	29	0	0	5.373D-08	0.0	0.0	0.0
57	29	32	0	0	5.070D-01	0.2	0.0	0.0
58	29	32	1	5	0.0	0.0	0.0	0.0

DEVIATION OF TOTAL ENERGY OF EACH MASS FROM 100 PERCENT

MASS	DEVIATION(PERCENT)
1	0.432690
2	0.195729
3	0.192711
4	0.097636
5	0.269269
6	0.011402
7	0.013419
8	-0.012181
9	0.040589
10	0.092927
11	0.128386
12	0.218863
13	-0.001528
14	-0.001745
15	0.0
16	0.066041
17	0.432690
18	0.195729
19	0.192711
20	0.097636
21	0.269269
22	0.011402
23	0.013419
24	-0.012181
25	0.040589
26	0.092927
27	0.128386
28	0.218868
29	-0.001528
30	-0.001745
31	0.0
32	0.066041

Figure 2-10. Sample Case Output, Time History Print (Sheet 9 of 11)

ELEMENT STRESSES

					RATIO OF CURRENT STRESS / FAILURE STRESS								RATIO OF CURRENT		
	BEAM				MAXIMUM SHEAR STRESS THEORY				THEORY OF CONSTANT ENERGY OF DISTORTION				AXIAL/FAILURE		BUCK. /
IJ	I	J	M	N	TOP	BOTTOM	LEFT	RIGHT	TOP	BOTTOM	LEFT	RIGHT	COMPR. STRESS	TENSILE STRESS	CR.BUCK. LOAD
1	1	2	0	0	9.670D-02	9.560D-02	6.891D-02	6.891D-02	9.052D-02	1.079D-01	5.587D-02	5.587D-02		5.130D-04	
2	2	3	0	0	1.345D-01	1.279D-01	7.048D-02	7.076D-02	1.259D-01	1.443D-01	5.714D-02	5.744D-02		3.076D-03	
3	3	4	0	0	3.746D-01	3.804D-01	1.372D-01	1.374D-01	4.227D-01	3.561D-01	1.340D-01	1.115D-01		2.699D-03	
4	4	5	0	0	1.469D-01	1.605D-01	3.200D-02	2.771D-02	1.658D-01	1.503D-01	2.703D-02	2.711D-02		6.377D-03	
5	5	6	0	0	2.025D-01	2.000D-01	1.016D-01	1.020D-01	2.285D-01	1.872D-01	8.260D-02	9.999D-02	1.436D-03		6.735D-05
6	7	8	0	0	4.211D-03	2.002D-03	3.416D-03	5.289D-03	3.905D-03	2.161D-03	3.554D-03	4.794D-03		1.132D-03	
7	8	9	0	0	5.064D-02	6.117D-02	4.869D-02	5.082D-02	5.712D-02	5.726D-02	4.765D-02	4.182D-02		4.933D-03	
8	9	10	0	0	2.714D-01	2.615D-01	2.098D-01	2.092D-01	3.062D-01	2.449D-01	2.052D-01	1.696D-01	5.582D-03		2.269D-04
9	10	11	0	0	5.598D-01	5.749D-01	4.958D-01	4.967D-01	6.315D-01	5.352D-01	4.846D-01	4.031D-01		7.081D-03	
10	11	12	0	0	6.058D-02	4.904D-02	1.044D-01	9.233D-02	6.686D-02	4.437D-02	1.158D-01	8.453D-02	7.343D-03		1.016D-04
11	1	17	0	0	9.770D-03	9.327D-03	2.467D-04	1.960D-04	1.102D-02	8.732D-03	2.784D-04	2.211D-04	2.497D-04		2.302D-04
12	2	18	0	0	2.554D-03	1.494D-03	3.268D-04	7.339D-04	2.882D-03	1.398D-03	3.687D-04	8.280D-04	5.983D-04		5.515D-04
13	3	19	0	0	1.142D-02	4.724D-02	1.716D-02	1.866D-02	1.069D-02	5.330D-02	1.936D-02	2.105D-02	2.020D-02		1.862D-02
14	4	20	0	0	2.600D-01	2.617D-01	6.061D-04	1.097D-03	2.434D-01	2.953D-01	6.838D-04	1.237D-03	9.606D-04		8.854D-04
15	5	21	0	0	2.180D-01	3.195D-01	5.123D-02	5.035D-02	2.040D-01	3.605D-01	5.780D-02	5.681D-02	5.730D-02		5.282D-02
16	6	22	0	0	3.232D-01	3.333D-01	1.209D-02	1.982D-03	3.025D-01	3.760D-01	1.364D-02	1.856D-03	5.704D-03		5.250D-03
17	1	7	0	0	2.281D-02	2.332D-02	1.299D-02	1.324D-02	2.136D-02	2.631D-02	1.091D-02	1.346D-02	2.863D-04		2.818D-04
18	2	8	0	0	4.719D-04	4.719D-04	9.581D-03	1.048D-02	5.261D-04	5.261D-04	8.969D-03	1.182D-02	5.066D-04		4.986D-04
19	3	9	0	0	6.345D-01	6.266D-01	3.367D-01	3.371D-01	7.159D-01	5.866D-01	2.731D-01	3.296D-01	4.474D-03		1.761D-02
20	4	10	0	0	5.486D-01	5.486D-01	2.215D-01	2.215D-01	6.190D-01	5.136D-01	2.166D-01	1.797D-01	2.854D-05		2.809D-05
21	5	11	0	0	6.813D-01	6.358D-01	3.367D-01	3.350D-01	7.687D-01	5.952D-01	3.296D-01	3.273D-01	2.566D-02		1.010D-01
22	6	12	0	0	6.024D-01	6.124D-01	2.518D-01	2.514D-01	5.639D-01	6.909D-01	2.461D-01	2.038D-01	5.667D-03		5.576D-03
23	3	16	0	1	1.129D-01	1.021D-01	9.205D-02	9.877D-02	2.160D-01	1.903D-01	1.733D-01	1.892D-01	8.901D-02		7.737D-04
24	5	16	0	2	2.580D-01	2.829D-01	1.994D-01	2.177D-01	4.993D-01	5.568D-01	4.020D-01	4.426D-01	3.523D-01		3.063D-03
25	9	16	0	3	1.385D-01	1.217D-01	1.075D-01	1.202D-01	2.823D-01	2.449D-01	2.227D-01	2.505D-01	2.198D-01		1.911D-03
26	11	16	0	4	2.154D-01	2.329D-01	1.901D-01	1.729D-01	4.316D-01	4.710D-01	3.995D-01	3.625D-01		3.662D-01	
27	13	14	0	0	3.647D-04	3.647D-04	3.647D-04	3.647D-04	4.115D-04	4.115D-04	4.115D-04	4.115D-04	4.115D-04		2.351D-05
28	13	15	0	0	8.012D-04	8.012D-04	8.012D-04	8.012D-04	1.702D-03	1.702D-03	1.702D-03	1.702D-03	1.702D-03		2.356D-04
29	5	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
30	11	13	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
31	13	16	0	0	1.381D 00	1.381D 00	1.381D 00	1.381D 00	1.558D 00	1.558D 00	1.558D 00	1.558D 00	0.0		0.0
32	13	16	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
33	17	18	0	0	9.670D-02	9.560D-02	6.891D-02	6.891D-02	9.052D-02	1.079D-01	5.587D-02	5.587D-02		5.130D-04	
34	18	19	0	0	1.345D-01	1.279D-01	7.076D-02	7.048D-02	1.259D-01	1.443D-01	5.744D-02	5.714D-02		3.076D-03	
35	19	20	0	0	3.746D-01	3.804D-01	1.374D-01	1.372D-01	4.227D-01	3.561D-01	1.115D-01	1.340D-01		2.699D-03	
36	20	21	0	0	1.469D-01	1.605D-01	2.771D-02	3.200D-02	1.658D-01	1.503D-01	2.711D-02	2.703D-02		6.377D-03	
37	21	22	0	0	2.025D-01	2.000D-01	1.020D-01	1.016D-01	2.285D-01	1.872D-01	9.999D-02	8.260D-02	1.436D-03		6.735D-05
33	23	24	0	0	4.211D-03	2.002D-03	5.289D-03	3.416D-03	3.905D-03	2.161D-03	4.794D-03	3.554D-03		1.132D-03	

Figure 2-10. Sample Case Output, Time History Print (Sheet 10 of 11)

39	24	25	0	0	5.064D-02	6.117D-02	5.082D-02	4.869D-02	5.712D-02	5.726D-02	4.182D-02	4.765D-02		4.933D-03	
40	25	26	0	0	2.714D-01	2.615D-01	2.092D-01	2.098D-01	3.062D-01	2.449D-01	1.696D-01	2.052D-01	5.582D-03		2.269D-04
41	26	27	0	0	5.593D-01	5.749D-01	4.967D-01	4.959D-01	6.315D-01	5.382D-01	4.031D-01	4.846D-01		7.081D-03	
42	27	28	0	0	6.058D-02	4.904D-02	9.233D-02	1.044D-01	6.686D-02	4.437D-02	8.463D-02	1.150D-01	7.343D-03		1.016D-04
43	17	23	0	0	2.281D-02	2.332D-02	1.324D-02	1.299D-02	2.136D-02	2.631D-02	1.346D-02	1.091D-02	2.863D-04		2.818D-04
44	18	24	0	0	4.719D-04	4.719D-04	1.048D-02	9.581D-03	5.261D-04	5.261D-04	1.182D-02	8.969D-03	5.066D-04		4.986D-04
45	19	25	0	0	6.345D-01	6.266D-01	3.371D-01	3.367D-01	7.159D-01	5.866D-01	3.296D-01	2.731D-01	4.474D-03		1.761D-02
46	20	26	0	0	5.486D-01	5.486D-01	2.215D-01	2.215D-01	6.190D-01	5.136D-01	1.797D-01	2.166D-01	2.854D-05		2.809D-05
47	21	27	0	0	6.813D-01	6.350D-01	3.350D-01	3.367D-01	7.687D-01	5.952D-01	3.273D-01	3.296D-01	2.566D-02		1.010D-01
48	22	28	0	0	6.024D-01	6.124D-01	2.514D-01	2.510D-01	5.639D-01	6.909D-01	2.038D-01	2.461D-01	5.667D-03		5.576D-03
49	19	32	0	1	1.129D-01	1.021D-01	9.877D-02	9.205D-02	2.160D-01	1.903D-01	1.892D-01	1.733D-01	8.901D-02		7.737D-04
50	21	32	0	2	2.580D-01	2.829D-01	2.177D-01	1.994D-01	4.993D-01	5.568D-01	4.426D-01	4.020D-01	3.523D-01		3.063D-03
51	25	32	0	3	1.385D-01	1.217D-01	1.202D-01	1.075D-01	2.823D-01	2.448D-01	2.505D-01	2.227D-01	2.198D-01		1.911D-03
52	27	32	0	4	2.154D-01	2.329D-01	1.729D-01	1.901D-01	4.316D-01	4.710D-01	3.625D-01	3.995D-01		3.662D-01	
53	29	30	0	0	3.647D-04	3.647D-04	3.647D-04	3.647D-04	4.115D-04	4.115D-04	4.115D-04	4.115D-04	4.115D-04		2.351D-05
54	29	31	0	0	8.012D-04	8.012D-04	8.012D-04	8.012D-04	1.702D-03	1.702D-03	1.702D-03	1.702D-03	1.702D-03		2.356D-04
55	21	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
56	27	29	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0
57	29	32	0	0	1.381D 00	1.381D 00	1.381D 00	1.331D 00	1.558D 00	1.558D 00	1.558D 00	1.558D 00	0.0		0.0
53	29	32	1	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		

Figure 2-10. Sample Case Output, Time History Print (Sheet 11 of 11)

PHI, THETA and PSI are the Euler angles defining the orientations of mass i with respect to the ground. These are positive right-wing-down, nose-up and nose-right, respectively. PHIDOT, THETADOT and PSIDOT are the time derivatives of the same angles. P, Q and R are the body axes components of the angular velocity of mass i, using the same sign convention as for the Euler angles. PDOT, QDOT and RDOT are the body axes components of the angular accelerations of mass i. None of these orientation quantities is output for the node points, since these are the same as for the mass to which a given node point is attached.

XIMPULSE, YIMPULSE, ZIMPULSE are the accumulated area under the filtered acceleration response curve (G-MSEC). Normally the user should plot this data to evaluate its meaning.

2.2.4.2 Beam Data

The STRAIN FORCES and TOTAL FORCES (STRAIN + DAMPING) are both output in the same format. FX, FY and FZ are the forces in beam axes acting upon the beam at the j end of the beam. Equal and opposite forces act upon the beam at the i end. MX is the torsion acting at the j end; again an equal and opposite torsion acts at the i end. MYI and MYJ are the bending moments at each end of the beam, acting about the beam y axis. MZI and MZJ are the moments acting about the beam z axis. In general, the moments acting at the i and j ends of the beam are not equal. The i and j ends of the beam are at masses i and j, unless the beam connects to a node point. In this case the i end of the beam is actually located at node point iM, and/or the j end at node point jN. M or N equal to zero means there is no node point; direct mass connection is used.

The beam X, Y and Z deflection data is presented in relative form, i.e., the values represent deflections at the j end minus those at the i end. The beam rotation data is given in both (J-I) and (J+I) terms. This is done because the strain forces are calculated using both sum and difference terms. Note that these angles are all in degrees, rather than radians. If the actual

rotations at the j and i beam ends are desired, they can be calculated from the output data as

$$\text{THETA(J)} = \frac{\text{THETA(J+I)} + \text{THETA(J-I)}}{2}$$

$$\text{THETA(I)} = \frac{\text{THETA(J+I)} - \text{THETA(J-I)}}{2}$$

Similar equations apply to PSI.

The Euler angles defining the current orientation of the beam axes are also output in degrees. To determine the current beam orientation, the following steps are required:

- Rotate PSI degrees about the ground fixed z axis, positive nose right
- Rotate THETA degrees about the new rotated y axis, positive nose up

2.2.4.3 External Spring Data

For each external spring, the spring compression in inches and compression load in pounds is output. These are along the spring axis, which is oriented parallel to one of the mass axes. The ground deflection is also shown; this deflection will be zero if the ground flexibility is input as zero. The ground contact point loads are given in two coordinate systems, ground axes and mass axes. If the spring in question is on a slope, then slope axes are used instead of ground axes. The output titles for these quantities are self-explanatory.

2.2.4.4 Energy Distribution Data

The first output in this section of data shows the current total system energy, kinetic energy, potential energy, strain energy, damping energy, crushing energy and friction energy. The next section of output shows the contributions of the individual masses, internal beams and external springs to these system totals. The system kinetic energy should reduce to zero at the conclusion of the analytical run. From a practical standpoint, however, one can expect individual elements to oscillate slightly after the vehicle

comes to rest, leaving some residual kinetic energy in the system long after the responses of interest have occurred. In general, it is anticipated that if the analysis shows a 75 percent reduction in kinetic energy, the most significant events will have been adequately described.

If the vehicle is impacting on a flat surface (no slope) and a substantial portion of the initial kinetic energy is due to forward velocity (parallel to the ground), then a much larger precentage of the initial kinetic energy may remain after the significant damage phase of the crash. The remaining energy is accounted for by the vehicle sliding along the ground with a substantial forward velocity. In this case, the vehicle cg translational velocities, printed earlier, provide a better indication of whether the major response phase has been adequately covered. In general, the ZDOT or vertical vehicle translational velocity should be reduced to zero, indicating that the vehicle has ceased its downward motion. This situation can also be seen when the system potential energy reaches a minimum.

The individual internal beam strain energies provide the user with valuable insight into the temporal and spatial flow of energy in the vehicle. Generally speaking, the strain energy concentrates initially near the point of impact, and as the strain energy grows it also becomes diffused throughout the vehicle. After the peak responses in the system occur, the overall system strain energy will decrease from its peak value as the internal beam elements unload.

Certain individual nonlinear beam elements may indicate negative strain energy. This circumstance may occur when large deflection loading and unloading occurs in the coupled bending degrees of freedom ($z-\theta$ or $y-\psi$), with nonlinear KR curves applied to these directions. This phenomenon is discussed in Section 1.3.16 of Volume I, and is due to the approximate nature of the nonlinear element analytical model. In practice, these negative strain energies are of such small magnitude relative to the overall system strain energy (usually less less than 1 percent) that they do not invalidate the overall analysis. Furthermore, these negative energies tend to occur toward the end of the analysis, during the unloading phase, after the primary responses and

damage of interest have been determined. It should also be noted that negative strain energy does not occur for linear beam elements, or for those that are nonlinear only in the uncoupled degrees of freedom (axial and torsion).

The damping energy of the internal beams is usually small in relation to the strain energy, typically being less than 20 percent of the strain energy, until late in the run when the strain energy has decreased substantially from its peak value. Note that damping energy always increases with time, since it is a dissipative energy that is not stored and released as with strain energy.

Crushing and friction energies result from the deformation of the external springs and flexible ground for the former, and from sliding friction along the ground for the latter. The friction energy is also dissipative and hence monotonically increasing, whereas the crushing energy peaks and decreases similar to the strain energy. In general, a rather large percentage of the total system energy may be represented by the crushing energy. This situation is only natural since the external springs represent the structure in immediate contact with the ground that undergoes substantial deformation. In a typical vehicle crash analysis, the system crushing energy may be larger than the internal beam strain energy. However, they both represent actual airplane structure, the only distinction being location on the vehicle.

The final energy information printed is a summary of the deviation of the total energy of each mass in the system from 100 percent. Ideally these variations should all be zero, but in actual practice errors associated with the numerical integration process result in deviations from the ideal. This information can be helpful for pinpointing areas of the mathematical model that may be causing numerical accuracy problems, and alerting the program user to the possible need for a finer integration time step.

In typical applications, a few individual mass total energies may deviate 2 - 5 percent from the 100 percent ideal, while the total energy of the entire system remains within 0.5 percent or less. This accuracy is

generally considered acceptable for the numerical integration process. However, the program user is free to adjust the integration time step to suit his own personal criterion for the accuracy of the individual mass integrations.

2.2.4.5 Internal Beam Stress Data

This output consists of ratios of current stress to failure level stress (corresponding to initial yielding), for four locations on each beam, using two failure theories. These theories are the maximum shear stress theory and the theory of constant energy of distortion. Section 1.3.17 of Volume I presents the method of calculating these ratios. Also shown in the output are the ratios of current compressive/tensile stress to the corresponding yield stress, and the ratio of current axial compressive load (when it is compressive) to the critical buckling load.

The stress data can be used as a guide for estimating the time at which the element begins to yield. When such a state is reached, a stiffness reduction factor (KR) may be developed for the affected member which then can be used to approximate the nonlinear response characteristics of that member. The user is cautioned to exercise extreme care in the interpretation of data presented in the summary since they do not include the effect of stress concentrations, geometric shape factors, and detail attachment practices at joints. In addition, limitations of the program require that gross regions of the vehicle structure be modeled using relatively simple structural elements. Thus, the more gross the structural region the less accurate the stress values. Also monitoring the response of a structural element which may exhibit a buckling mode of failure will require special consideration. In this case the critical buckling load becomes significant and a stiffness reduction factor should be developed which will approximate the buckling characteristics of the element.

Furthermore, the user should realize that once an element has yielded or buckled, the failure theories followed become invalid and, consequently, the most meaningful use of the response data is to identify which element may fail and at what point in time such failures are apt to occur.

2.2.5 Summaries

At the conclusion of the time history printout several summaries are presented, which include:

- Summary of internal beam yielding and rupture
- Summary of mass penetration into a control volume
- Summary of plastic hinge moment formations
- Summary of external spring loading and unloading
- Summary of energy distribution

The summaries are illustrated in Figure 2-11.

Internal beam element yielding and rupture are summarized at the end of the run. For each occurrence of yielding or rupture, the time, beam identification and beam direction of yielding or rupture is output. Directions 1-6 correspond to beam axis directions x, y, z, ϕ, θ and ψ, the latter three being rotations about the beam x, y and z axes. In addition the beam tension and compression rupture is noted. If a beam has a special KR curve that starts at a nonzero value, then this summary will indicate yielding at time zero. This output provides the user with a concise summary of the onset of beam nonlinearities and beam ruptures. Any mass penetrations into the mass penetration control volume are also summarized. Both the mass penetrating the control volume and time of occurrence are noted.

For the plastic hinge summary the time of occurrence, beam designations, the end at which the hinge forms and the direction (bending about Y(5), or Z(6).

The summary of external spring loading and unloading provides the time of occurrence, the spring designations (mass, node, direction), type of event, initial deflection, maximum force and deflection and unloaded force.

The energy summary showing the time variation of the different types of energy is presented. This summary facilitates visualizing the energy flow time variation; the one or two page summary is much easier to read than skimming through the basic time history print, which can run to hundreds of pages. Figure 2-11 shows an example of this output for the sample case. A quick glance at the "PERCENT TOTAL SYSTEM ENERGY" column tells the user how stable

SUMMARY OF EXTERNAL SPRING LOADING AND UNLOADING

TYPES;1=INITIAL LOADING 2=MAX.LOADING 3=UNLOAD TO ZERO FORCE 4=INITIATION OF RELOAD

NOTE:SPRING RELOADS AT ZERO FORCE(SEQ.1,2,3,4) OR AT FINITE FORCE VALUE(SEQ.1,2,4)

NOTE:INITIAL DEFLECTION IS FIRST IMPACT IF NYPE=1, OTHERWISE IT IS POINT AT WHICH RELOADING OCCUR FOR NTYPE=4

TIME(SEC)	MASS NO.	NODE NO.	DIRECTION L=1,2,3	TYPE NO.	INITIAL DEFLECTION	MAXIMUM FORCE	&/OR DEFLECT	UNLOADED DEFLECT	& FORCE
0.000010	6	0	3	1	0.0023	0.0	0.0	0.0	0.0
0.000010	22	0	3	1	0.0023	0.0	0.0	0.0	0.0
0.000290	5	0	3	1	0.0025	0.0	0.0	0.0	0.0
0.000290	21	0	3	1	0.0025	0.0	0.0	0.0	0.0
0.000720	4	0	3	1	0.0010	0.0	0.0	0.0	0.0
0.000720	20	0	3	1	0.0010	0.0	0.0	0.0	0.0
0.001190	3	0	3	1	0.0003	0.0	0.0	0.0	0.0
0.001190	19	0	3	1	0.0003	0.0	0.0	0.0	0.0
0.001640	2	0	3	1	0.0029	0.0	0.0	0.0	0.0
0.001640	18	0	3	1	0.0029	0.0	0.0	0.0	0.0

SUMMARY OF PLASTIC HINGE FORMATIONS

TIME	BEAM IJ	I	J	M	N	BEAM END MASS NO.	DIRECTION
0.000660	22	6	12	0	0	12	5
0.000660	43	22	28	0	0	28	5
0.001310	20	4	10	0	0	4	5
0.001310	46	20	26	0	0	20	5
0.002010	19	3	9	0	0	9	5
0.002010	45	19	25	0	0	25	5

CONTROL VOLUME PENETRATIONS

TIME	MASS
0.00001	15

SUMMARY OF INTERNAL BEAM YIELDING AND RUPTURE

TIME	BEAM IJ	I	J	M	N	BEAM DIRECTION FOR YIELD	RUPTURE	TENSION(+) OR COMPRESSION(-)
0.000020	10	11	12	0	0	0	1	1
0.000020	43	28	29	0	0	0	1	1

Figure 2-11. Sample Case Output, Summary Prints (Sheet 1 of 2)

SUMMARY OF ENERGY DISTRIBUTION

TIME	PERCENT MAXIMUM ENERGY DEVIATION	PERCENT TOTAL SYSTEM ENERGY	KINETIC ENERGY	PERCENT OF CURRENT TOTAL	POTENTIAL ENERGY	PERCENT OF CURRENT TOTAL	STRAIN ENERGY	PERCENT OF CURRENT TOTAL	DAMPING ENERGY	PERCENT OF CURRENT TOTAL	CRUSHING ENERGY	PERCENT OF CURRENT TOTAL	FRICTION ENERGY	PERCENT OF CURRENT TOTAL
.0	0.0	100.00	7.695E 04	84.95	1.364E 04	15.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
.00100	0.290289	100.02	7.519E 04	82.99	1.346E 04	14.85	1.309E 02	0.14	1.073E 01	0.01	1.813E 03	2.00	0.0	0.0
.00200	0.432690	100.04	7.014E 04	77.40	1.328E 04	14.66	2.922E 02	0.32	4.429E 01	0.05	6.867E 03	7.58	0.0	0.0

Figure 2-11. Sample Case Output, Summary Prints (Sheet 2 of 2)

the solution is. The percent energy should stay within 95 - 105 percent, preferably within a ± 0.5 percent band. Any significant system instabilities will quickly manifest themselves in this output.

The column entitled "PERCENT MAXIMUM ENERGY DEVIATION" shows the maximum deviation from 100 percent of the total energy for each mass individually, i.e., at each time the worst deviation of all the masses is shown. These numbers will always indicate a greater departure from 100 percent than the "PERCENT TOTAL SYSTEM ENERGY" column, wherein all the masses constituting the system are included. The reason for this situation is that some of the masses have positive and some negative deviations from 100 percent, and when these are summed over the total system cancellations occur. Individual mass total energy deviations in the order of 10 percent may be tolerable, as long as the total system energy is acceptable.

2.2.6 Time History Plots

The final section of output data consists of time history plots of selected response quantities. Figure 2-12 illustrates typical output data. The sequential time history print of the three responses is shown on the left, while the plots are generated using three separate printer symbols. The scale factor for all three plots is shown in the upper right corner of the page. The plot summary is printed on a separate output page as are the various sets of data. For illustrative purposes several plots have been combined.

```
5  MASS PLOT FLAG SUMMARY
    1      0      0      0      0      0      1      1      0      1
    3      0      0      0      0      0      1      1      0      0
   13      0      0      0      0      0      1      1      0      0
   14      0      0      0      0      0      1      1      0      0
   16      0      0      0      0      0      1      1      0      1

     MASS   1   UNFILTERED ACCELERATION(G'S)

TIME(SEC)  XACC       YACC       ZACC
             *          =          +
                                                                        SCALE FACTOR = 4.439E 01
.............................................................................................I.........I
 0.0      -1.310E-02 0.0        9.999E-01
 0.001    -7.889E-01-4.274E-02-1.524E 00                                                               +
 0.002    -9.584E 00-1.057E-01-3.719E 02      +                                                       +=
                                                                                                      * =

     MASS   1   FILTERED ACCELERATION(G'S)

TIME(SEC)  XACCF      YACCF      ZACCF
             *          =          +
                                                                        SCALE FACTOR = 3.460E 00
.............................................................................................I.........I
 0.0       0.0        0.0        0.0
 0.001    -1.020E-01 4.117E-02-2.369E-01                                                               +
 0.002    -3.287E 00 1.567E-02-2.903E 01      +                                                       +=
                                                                                             *         =

     MASS   1   MASS IMPULSES

TIME(SEC)  XIMP       YIMP       ZIMP
             *          =          +
                                                                        SCALE FACTOR = 2.718E-04
.............................................................................................I.........I
 0.0       0.0        0.0        0.0
 0.001    -1.222E-04 3.457E-05 1.123E-04                                               +
 0.002    -1.556E-03 5.756E-05 7.269E-04      *                                    *   . = +
                                                                                       . =              +
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 1 of 6)

```
1  NODE PLOT FLAG SUMMARY
         1       13       1       1       1       1       1       0


      MASS  13   NODE   1   DISPLACEMENTS(IN)

 TIME(SEC)      X          Y          Z
                *          =          +                                                                        SCALE FACTOR = 3.571E 00
.......................................................................................................................I.........I
  0.0      -3.704E 00-1.300E 01-2.999E 01    +                                        =                      *
  0.001    -3.704E 00-1.300E 01-2.966E 01     +                                       =                      *
  0.002    -3.704E 00-1.300E 01-2.933E 01      +                                      =                      *

      MASS  13   NODE   1   VELOCITY(IN/SEC) - GROUND AXES

 TIME(SEC)  XDOT       YDOT       ZDOT
             *          =          +                                                                           SCALE FACTOR = 3.937E 01
.......................................................................................................................I.........I
  0.0      -6.661E-16 0.0       3.300E 02    =                                                                           +
  0.001    -8.737E-05-1.149E-05 3.304E 02    =                                                                           +
  0.002    -8.830E-04 1.448E-05 3.307E 02    =                                                                           +

      MASS  13   NODE   1   VELOCITY(IN/SEC) - MASS AXES

 TIME(SEC)      U          V          W
                *          =          +                                                                        SCALE FACTOR = 3.988E 01
.......................................................................................................................I.........I
  0.0      -4.323E 00 0.0       3.300E 02    *=                                                                          +
  0.001    -4.328E 00-1.149E-05 3.304E 02    *=                                                                          +
  0.002    -4.333E 00 1.448E-05 3.307E 02    *=                                                                          +

      MASS  13   NODE   1   UNFILTERED ACCELERATION(G'S)

 TIME(SEC)  XACC       YACC       ZACC
             *          =          +                                                                           SCALE FACTOR = 1.206E-01
.......................................................................................................................I.........I
  0.0      -1.310E-02 0.0       9.999E-01    *=                                                                          +
  0.001    -1.310E-02 1.190E-06 9.641E-01    *=                                                                        +
  0.002    -1.332E-02 2.945E-04 6.867E-01    *=                                                          +

      MASS  13   NODE   1   FILTERED ACCELERATION(G'S)

 TIME(SEC)  XACCF      YACCF      ZACCF
             *          =          +                                                                           SCALE FACTOR = 1.206E-01
.......................................................................................................................I.........I
  0.0      -1.310E-02 0.0       9.999E-01    *=                                                                          +
  0.001    -1.311E-02-1.084E-05 9.951E-01    *=                                                                          +
  0.002    -1.313E-02 2.611E-05 9.303E-01    *=                                                                      +
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 2 of 6)

```
  2  BEAM FORCE PLOT FLAG SUMMARY
          19       1       1       1
          20       1       1       1


     BEAM  19   I,M =   3, 0     J,N =   9, 0     AXIAL AND SHEAR FORCES(LB)

TIME(SEC)   FX         FY         FZ
            *          =          +                                                                    SCALE FACTOR = 1.330E 02
.....................................................................................................................I.........I
 0.0       0.0        0.0        0.0           +
 0.001     8.116E 00 8.940E-03-3.900E 01     +  =*
 0.002    -3.812E 01 7.284E-01 1.078E 03     *  =                                                                   +

     BEAM  19   I,M =   3, 0     J,N =   9, 0     MOMENTS AT I,M(IN-LB)

TIME(SEC)   MX         MY         MZ
            *          =          +                                                                    SCALE FACTOR = 9.485E 02
.....................................................................................................................I.........I
 0.0       0.0        0.0        0.0               +
 0.001     1.977E 01-2.722E 02-6.498E-02       =   +
 0.002    -5.279E 02 7.440E 03-5.176E 00     *     +                                                                =

     BEAM  19   I,M =   3, 0     J,N =   9, 0     MOMENTS AT J,N(IN-LB)

TIME(SEC)   MX         MY         MZ
            *          =          +                                                                    SCALE FACTOR = 9.740E 02
.....................................................................................................................I.........I
 0.0       0.0        0.0        0.0              +
 0.001     1.977E 01-2.738E 02-6.018E-02       = +*
 0.002    -5.279E 02 7.653E 03-5.020E 00     *    +                                                                 =
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 3 of 6)

```
   2  BEAM DEFLECTION PLOT FLAG SUMMARY
        19        1       1       1
        20        1       1       1


     BEAM  19   I,M =    3, 0      J,N =    9, 0     RELATIVE DEFLECTIONS*J-I*(IN)

TIME(SEC)    X          Y          Z
             *          =          +                                                                              SCALE FACTOR = 3.152E-03
..............................................................................................................................I.........I
 0.0      0.0        0.0        0.0         +
 0.001    5.120E-05 1.013E-05-8.637E-04   + =
 0.002   -2.058E-04 1.411E-03 2.561E-02     *.  =                                                                                      +


     BEAM  19   I,M =    3, 0      J,N =    9, 0     RELATIVE ROTATIONS*J-I*(DEGREE)

TIME(SEC)   PHI        THETA       PSI
             *          =          +                                                                              SCALE FACTOR = 1.083E-02
..............................................................................................................................I.........I
 0.0      0.0        0.0        0.0                                                                                           +
 0.001    2.749E-03-5.190E-05 1.100E-05                                                                                       + *
 0.002   -8.294E-02 8.018E-03 4.162E-04   *                                                                                   +     =


     BEAM  19   I,M =    3, 0      J,N =    9, 0     RELATIVE POTATIONS*J+I*(DEGREE)

TIME(SEC)   FHI        THETA       PSI
             *          =          +                                                                              SCALE FACTOR = 1.020E-02
..............................................................................................................................I.........I
 0.0      0.0        0.0        0.0                                                                                              +
 0.001    2.749E-03 1.507E-04-2.665E-05                                                                                          +  *
 0.002   -8.294E-02-1.041E-02-1.147E-03   *                                                                               =     +.
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 4 of 6)

```
   1  BEAM STRESS PLOT FLAG SUMMARY
            8        1        1        1        0        0

     BEAM   8   I,M =    9, 0     J,N =  10, 0     STRESS RATIO (MAXIMUM SHEAR STRESS THEORY) AT TOP AND BOTTOM OF BEAM

TIME(SEC)   TOP        BOTTOM
             *           =
                                                                                                        SCALE FACTOR = 2.888E-02
.......................................................................................................................I.........I
 0.0       0.0         0.0             =
 0.001     5.666E-03 7.271E-03        . *=
 0.002     2.714E-01 2.615E-01        .                                                                                  =  *

     BEAM   8   I,M =    9, 0     J,N =  10, 0     STRESS RATIO (THEORY OF CONST. ENERGY OF DIST.) AT TOP AND BOTTOM OF BEAM

TIME(SEC)   TOP        BOTTOM
             *           =
                                                                                                        SCALE FACTOR = 3.258E-02
.......................................................................................................................I.........I
 0.0       0.0         0.0             =
 0.001     6.392E-03 6.807E-03        . =
 0.002     3.062E-01 2.449E-01        .                                                                   =                 *

TIME(SEC)   LEFT       RIGHT
             *           =
                                                                                                        SCALE FACTOR = 2.232E-02
.......................................................................................................................I.........I
 0.0       0.0         0.0             =
 0.001     5.085E-03 5.123E-03        . =
 0.002     2.098E-01 2.092E-01        .                                                                                     =
   4  EXTERNAL SPRING PLOT FLAG SUMMARY
            3        0        1        1
            4        0        1        1
            5        0        1        1
            6        0        1        1

     EXTERNAL SPRING    I,M =    6, 0      COMPRESSION(IN)

TIME(SEC)   X          Y          Z
            *          =          +
                                                                                                        SCALE FACTOR = 6.480E-02
.......................................................................................................................I.........I
 0.0       0.0        0.0        0.0           +
 0.001     0.0        0.0        2.809E-01     =                                        +
 0.002     0.0        0.0        5.443E-01     =                                                                            +

     EXTERNAL SPRING    I,M =    6, 0      AXIAL LOAD(LB)

TIME(SEC)   X          Y          Z
            *          =          +
                                                                                                        SCALE FACTOR = 2.095E 02
.......................................................................................................................I.........I
 0.0       0.0        0.0        0.0           +
 0.001     0.0        0.0        1.760E 03     =                                                                            +
 0.002     0.0        0.0        1.760E 03     =                                                                            +
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 5 of 6)

```
     2  STRAIN AND DAMPING PLOT FLAG SUMMARY
              2        1         1
              4        1         1


   BEAM  2   I,M=    2, 0      J,N=    3, 0      STRAIN ENERGY AND PERCENT

TIME(SEC)   SE         %
            *          =                                                             SCALE FACTOR = 6.291E-02
..............................................................................................I.........I
 0.0      0.0       0.0          =
 0.001    4.760E-03 3.636E-03     .=
 0.002    5.914E-01 2.024E-01    .                             =                                        *
   BEAM  2   I,M=    2, 0      J,N=    3, 0      DAMPING ENERGY AND PERCENT

TIME(SEC)   DE         %
            *          =                                                             SCALE FACTOR = 2.271E-02
..............................................................................................I.........I
 0.0      0.0       0.0          =
 0.001    4.287E-04 3.996E-03    * =
 0.002    9.456E-02 2.135E-01    .                                       *                             =

     1  DRI PLOT FLAG SUMMARY
           15


   DRI MASS  15

TIME(SEC)   DRI
             *                                                                        SCALE FACTOR = 7.860E-05
..............................................................................................I.........I
 0.0       0.0                                                                                          *
 0.001    -4.802E-04                                          *                                         .
 0.002    -8.175E-04     *                                                                              .


   VEHICLE C.G. VELOCITY(IN/SEC)

TIME(SEC)    X          Y          Z
             *          =          +                                                  SCALE FACTOR = 3.929E 01
..............................................................................................I.........I
 0.0      -6.661E-16 0.0        3.300E 02    =
 0.001    -2.379E-04-3.084E-17 3.268E 02    =                                                          +
 0.002    -4.712E-04 2.467E-16 3.171E 02    =                                                        +
                                                                                                    +
```

Figure 2-12. Sample Case Output, Time History Plots (Sheet 6 of 6)

SECTION 3

MATH MODEL DEVELOPMENT PROCEDURES

3.1 OBJECTIVES

Program KRASH is designed to provide the user with a practical engineering approach to determine the crashworthiness capabilities of vehicles. The user should be aware that the features of the program are:

- KRASH provides data from which an assessment can be made of the occupant's chances of survival in a crash environment.
- Load-deflection behavior can be approximated using good engineering judgment.
- An analysis should be premised on the fact that only a portion of the major structural elements need be modeled in the post-failure region.
- Critical regions can be identified and approximate post yield behavior can be selected from available options in KRASH.

Program KRASH's formulation is consistent with the amount and quality of detailed data that are available during a preliminary design study. Furthermore, the analyses during preliminary design studies can serve to:

- Ascertain critical regions wherein alterations to element response will be most beneficial.
- Determine the extent to which additional energy absorption is needed.
- Determine the sensitivity of changes in crash environment, mass locations and structural characteristics with regard to crashworthiness capability.
- Determine the structural element load-deflection characteristics and, consequently, structural design and size requirements that are needed to meet a specified or desired crashworthiness criterion.

To effectively use Program KRASH, the user can benefit from a set of guidelines in establishing a math model. The following section provides an

outline of a recommended procedure for establishing a math model using program KRASH.

3.2 GENERAL PROCEDURE

The general step by step procedure for developing a math model to be used in KRASH is shown in Table 3-1 and described briefly as follows:

1. Define the Crash Environment - Initial Conditions (velocities, angles, angular rates, ground slope, airplane position relative to the ground contact point).

2. Estimate the energy that has to be absorbed based on vehicle mass, mass inertia properties, translational and rotational velocities.

3. Define the expected order of failure and/or deformation of critical structure and the regions in which they are located with regard to their potential effect on occupant safety. Generally, critical regions are where the initial impact takes place and/or are associated with the occupant cabin area.

4. Define the types of elements that are involved in the critical regions and the anticipated load deformation behavior of each. At this point only a general definition of the post-failure behavior is required. While nonlinear behavior can be complex, it is suggested that general post-failure curves be established for axial, torsion, and bending in two planes be considered for each internal element. For structure that is expected to contact the ground, define the orientation and length of external springs which will be used to represent crushable structure.

5. Layout a model representation of the structure incorporating the major elements and define the mass point locations.

6. Estimate mass properties and linear stiffness properties for each of the members using typical cross sections to compute area and material properties (E, G, A, I_x, I_y). For structure that potentially contacts the ground, the overall load-deflection characteristics should be estimated using available test and/or analytical data. For other than concrete surfaces, the stiffness characteristics of the terrain have to be approximated.

7. Estimate nonlinear characteristics. Use program calculation of preliminary loads and deflections as a guide to initial selection of values.

TABLE 3-1. PROCEDURE OUTLINE FOR DEVELOPING A MATH MODEL USING KRASH

PROCEDURE	GENERAL DESCRIPTION
1. Definition of Crash Environment	Initial Conditions, Terrain
2. Estimate of Energy Absorption	Vehicle Mass, inertia properties initial impact conditions
3. Identification of Critical Structure	Potential for occupant survival
4. Definition of Element Types	General nonlinear load-deflection characteristics
5. Math Model Layout	Nodes, masses, springs, elements
6. Estimate of Mass and Stiffness Properties	Determine masses, inertias, stiffness, materials
7. Select nonlinear characteristics	Use preliminary load and deflection data as a guideline
8. Estimate Failure cutoffs	Failure deflections and/or loads
9. Damping Coefficients	Select percent critical damping for beams
10. Initial Computer run (max. time = 0)	Review model input data
11. Review Model Parameter Data	Overall mass properties frequencies, damping
12. Revise Input Data, if required	Based on results of preliminary run
13. Select Integration Interval	Based on member frequencies
14. Limited Computer Run ($T_{max} \leq 0.010$ seconds)	Check validity and stability of model
15. Revise Model (if required)	Based on results of computer run

TABLE 3-1. PROCEDURE OUTLINE FOR DEVELOPING A MATH MODEL USING KRASH (Continued)

PROCEDURE	GENERAL DESCRIPTION
16. Select Data Requirements	Choose print/plot options
17. Perform Extended Runs	Incorporate "restart" capability
18. Review Rupture Summary Data	Determine if yields, and/or failures are consistent
19. Review Energy Data	Determine if spatial and temporal distribution are appropriate
20. Revise Model as Required	Revise nonlinearities, crushable structure, and/or failure limits, as required. Utilize "Restart"
21. Finalize Model	Determine run time and data to be obtained

8. Estimate failure loads for the various critical elements. Using the linear stiffness data, determine the appropriate failure deflections. Program KRASH computes uncoupled failure loads and deflections and this data can be used as a first estimate for input.

9. Provide damping coefficients for all the members. It is suggested that initially values of 0.01 to 0.04 be used for all members.

10. Set up the KRASH data deck and run a case for a time = 0 printout. Set the integration interval at Δt = 0.00003 seconds. Although one may be interested in establishing a relatively large model (~50 masses, ~100 members), it is advisable to first make a trail run with an abbreviated version of the math model. The smaller model can take advantage of the symmetry of the airplane to reduce the model size to about 60 percent of the ultimate model. While it may not be used to obtain final results, it will provide insight into modeling requirements in a more economic manner than the larger model.

11. Review the model parameter data to check overall vehicle mass properties, cg location, member frequencies and vehicle position relative to the ground.

12. Revise the math model mass and/or coordinate positions if they are not compatible with the airplane properties.

13. Select an initial integration interval. A rule of thumb for selecting a final integration interval is the following:

$$\Delta t \leq 0.01/\text{Maximum Frequency (Hz)}$$

Typical problems require integration intervals between 1×10^{-5} and 3×10^{-5}. In establishing the math model it is best to avoid (if possible) members whose frequency will exceed 500 Hz. A review of the model parameter data printout will help the user determine which members have the potential to cause integrating associated problems.

14. Make an initial computer run for a limited time(TMAX $\leq$ 0.010) and a print interval of 50 to 100 times Δt. Check the output data with regard to:

- External spring deflections and forces
- Individual element energies
- Overall energy contributions
- Selected member forces and deflections

In this check the user is primarily concerned with the validity of initial results (symmetry, magnitude, directions, energy distribution) and whether potential instability problems may occur (i.e., energy growth, negative energy). Later in this section a discussion on how to troubleshoot and rectify potential stability problems is presented.

15. Revise the model, as required.

16. Select the data to be printed and/or plotted. This includes mass, beam, spring, and energy data.

17. Once the user has determined that the basic model that has been established is valid, more extended time runs should be made. While it is possible to make one complete computer run with the initial math model, it is more likely that several runs will be required. Generally it is desirable to check the model at various stages of time(i.e., TMAX = 0.040, 0.080, 0.120, 0.160) to make sure selection of nonlinear elements is consistent with the type of crash condition that is being analyzed. The user can take advantage of the "restart" capability in KRASH to build the model up in stages.

18. Review the rupture summary data.

19. Compare the energy absorption capability of the structure to the amount of kinetic energy that has to be absorbed. Crushing and ground friction generally account for more than 50 percent of the total energy, with strain, damping and potential energy changes accounting for the difference. In general it will suffice to account for dissipating the energy associated with the vertical descent rate. This occurs when the vertical component of the translational velocity reaches zero. For most crash conditions (except overturns) this requires an analysis of between 100 and 150 milliseconds crash duration.

20. Revise model, if necessary; might require varying of crushable structure load-deflection characteristics, nonlinear curves and/or failure limits.

21. Finalize model and select output data; i.e., stress, DRI, acceleration.

Table 3-2 provides a format which will aid the user in determining the size of the model needed, what regions of the airframe are critical, whether to use external spring or internal element representations and the primary sources of available data. For a particular accident condition and airplane to be analyzed, the user, by following the format shown in Table 3-2, can define, in general terms, the relative significance of modeling different portions of the structure using program KRASH. Table 3-3 illustrates how the table would appear with data that is applicable to a single-engine, high-wing airplane which is to be modeled for a stall spin crash accident. From the general description contained in Table 3-3, it can be noted that for the accident of interest and airplane considered, the representation of the forward fuselage, cabin area, lower fuselage, engine mount, and seat system have the predominant influence on occupant survivability. In particular the fuselage structure, due to the large amount of energy that is absorbed in deforming, requires that proper load-deflection characteristics be represented. On the other hand, due to the nature of the impact conditions associated with this accident and their location (for this airplane configuration) relative to the occupant's livable volume, structural regions such as the aft fuselage, tail unit, and wing structure need not be rigorously modeled, since their failure behavior does not pose a threat to the safety of the occupants.

TABLE 3-2. FORMAT TO ASSIST IN ESTABLISHING MODEL TO BE USED WITH KRASH

STRUCTURE OR REGION	RELATIVE AMOUNT OF STRUCTURAL DEFORMATION	STRUCTURAL FAILURE OCCURRENCE	RELATIVE AMOUNT OF ENERGY ABSORBED	INFLUENCE ON OCCUPANT SURVIVABILITY	PROBABLE SOURCE OF DATA PRIMARY SECONDARY	REPRESENTATION IN KRASH	
						EXTERNAL SPRING	INTERNAL MEMBER
Forward Fuselage							
Mid Fuselage Lower Structure							
Mid Fuselage Cabin Area							
Mid Fuselage Top Area							
Seat and Restraint System							
Engine Mount Support Forward Fuselage							
Engine Mount Support Wing Structure							
Wing Structure - High							
Wing Structure - Low							
Landing Gear							
Aft Fuselage							
Tail Sections - Vertical and Horizontal							

TABLE 3-3. SAMPLE COMPLETED TABLE FOR SINGLE-ENGINE, HIGH-WING AIRPLANE

STRUCTURE OF REGION	RELATIVE AMOUNT OF STRUCTURAL DEFORMATION	STRUCTURAL FAILURE OCCURRENCE	RELATIVE AMOUNT OF ENERGY ABSORBED	INFLUENCE ON OCCUPANT SURVIVABILITY	PROBABLE SOURCE OF DATA PRIMARY SECONDARY	REPRESENTATION IN KRASH	
						EXTERNAL SPRING	INTERNAL MEMBER
Forward Fuselage	Large	Frequently	High	Strong	Analysis/Test	X	
Mid Fuselage Lower Structure	Moderate/Large	Frequently	Small/Moderate	Moderate/Strong[f]	Analysis/Test	X	
Mid Fuselage Cabin Area	Moderate	Sometimes	Moderate/Large	Strong	Analysis/Test		X
Mid Fuselage Top Area	Minor[a]	Sometimes	Small	Moderate[a]	Analysis/Test	X[d]	X
Seat	Moderate	Sometimes	Small	Strong	Test/Analysis		X
Engine Mount Support Forward Fuselage	Large	Frequently	Small	Strong	Test/Analysis		X
Wing Structure - High	Minor	Sometimes	Small[b]	Little	Test/Analysis	X[d]	X
Landing Gear[f]	Moderate/High	Rarely	Moderate	Moderate/Strong[c]	Test/Analysis	X[e]	X
Aft Fuselage	Moderate	Sometimes	None/Small	None/Little	Test/Analysis		X
Tail Sections - Vertical and Horizontal	Minor	Frequently	None/Small	None/Little	Test/Analysis	X[d]	X

(a) Except for inverted case

(b) Except when separated from fuselage attach points

(c) Except for penetration into occupiable area

(d) For selected accident conditions

(e) Tire stiffness

(f) Non retractable spring type cantilevered gear attached at Fuselage bulkhead

Impact Condition for stall accident type.
Flight path impact velocity ≥ Stall speed, Airplane Pitch Angle ≤ 30
Flight path angle ≤ 30 degrees nose up, Roll and yaw angles ≤ 10 degrees.
Terrain is concrete or hard ground.

3.3 INPUT DATA REQUIREMENTS

Program KRASH requires the following information:

- A set of control cards which includes information regarding impact conditions, problem size, print and plot controls, model symmetry, impact surface slope and type, integration interval and duration of analysis.
- Mass data including coordinates, mass and inertia properties and node point locations.
- External spring data including attachment mass identification and direction in which spring acts, free length, ground coefficient of friction, ground flexibility bottoming spring rate and associated plow force, and load-deflection characteristics.
- Internal beam data including beam member identification, beam area, material and damping properties, and nonlinear deflection characteristics.
- Failure data including maximum force or deflection rupture values.
- Dynamic Response Index (DRI) identification.
- Volume change and penetration data.
- Miscellaneous optional data including nonzero values of aerodynamic lift, angular momenta of rotating masses and cross products of mass inertial, acceleration pulse time histories, and direct input of the individual element stiffnesses.

Input data are described in detail in Section 2.

Brief discussions related to the proper interpretation and application of the input data are provided in Section 4 of this report.

3.4 OUTPUT DATA AVAILABLE

Program KRASH provides, at each time interval of designated print, the following data with which the user can evaluate the structural crashworthiness of vehicles:

- Mass response data including position, velocity and acceleration as a function of time in ground and airplane axes.
- Internal beam strain and total forces (strain plus damping) and displacements in six directions, as well as relative rotations.

- External spring compression, axial load, ground deflection and ground contact loads in ground and mass axes.

- DRI number for each DRI element (optional).

- Overall vehicle cg translational velocity (3 directions).

- Volume change data (optional).

- Energy distribution by mass (kinetic and potential), beam (strain, damping) and spring (crushing, friction).

- Stress output for each element (optional).

In addition the program provides the following output data:

(a) At the outset of the analysis one time print of Model Parameter Data. These data include vehicle weight, cg location, overall mass inertia properties, vehicle position at ground contact, beam frequencies and damping coefficients, and an optional print of calculated uncoupled yield forces and deflections.

(b) Print and plot (3 per page) end of the run summaries of each of the continuous time print data. A summary print of yielded and ruptured members and the times at which the event takes place is also provided, as is an energy summary print.

The output data are described, in detail, in Section 2.

To assist the user in obtaining data, as well as for understanding the use of the data and interpretation of the results, Table 3-4 is provided. Table 3-4 shows where information related to pertinent areas of interest are located in the three volumes which comprise the KRASH User's Manual.

TABLE 3-4. USER'S MANUAL INDEX

AREA OF INTEREST	APPLICABLE USER'S MANUAL SECTIONS		
	VOLUME I	VOLUME II	VOLUME III
• Crash Environment-Impact Conditions, Terrain	1.3.15, 1.3.5.4.3	2.1, 2.2.2, 2.2.4, 4.2, 4.12, 4.13	2.3, 2.4
• Energy Absorption-Components	1.3.16	4.14, 2.2.4.4	4.3
• Structural Behavior-Failure Nonlinear Characteristics	1.3.5.3.4	2.1, 4.7, 4.5.2	1.5, 4.3
• Model Layout		2.1, 2.2.4.1,	1.4
Nodes	1.3.1	4.3, 4.4, 4.5	
Members	1.3.1	2.1, 2.2.4.2, 4.6	
• Input Data:		2.1	1.5
Materials		4.5.1	
Mass Properties	1.3.7	4.3	
Linear Stiffness Damping Values	1.3.5.3.2 1.3.5.3.6	4.5.1	
KR Factors	1.3.5.3.4	4.5.2	
External Springs	1.3.5.4	4.4	
• Beam Frequencies	1.3.5.3.6	2.2.3	
• Integration Interval	1.3.13	4.14	
• Instability	1.3.13	2.2.4.4, 4.14	
• Failure Deflection, Loads, Rupture		2.2.3, 2.2.5	4.3.1
• Volume-Penetration, Change	1.3.10 1.3.11	2.2.4, 4.9	3.4
• Occupant Response, DRI, Movement, Severity Indices	1.3.12	2.1, 2.2.4, 4.10	3.3, 3.4

TABLE 3-4. USER'S MANUAL INDEX (Continued)

AREA OF INTEREST	APPLICABLE USER'S MANUAL SECTIONS		
	VOLUME I	VOLUME II	VOLUME III
• Output Data			-
Mass responses		2.0	
Beam Forces, Displacements		2.0	
Energy		2.0	
External Springs		2.0	
cg Velocity		2.0	

SECTION 4

KRASH DATA REQUIREMENTS

4.1 PROGRAM OUTPUT CONTROLS

Program output controls are provided to give the user flexibility in reviewing pertinent data associated with a KRASH analysis. The program can provide a mountain of data, if desired. However, experience has shown that only a portion of the data available for output is absolutely necessary to evaluate the vehicle's structural crashworthiness capability for any particular crash situation. The program is set up to provide a minimum amount of print. Using the appropriate output controls the user may select any amount of additional data desired. For example, the user can obtain all the output print at each time interval by exercising one computation code (stresses) and seven print controls (responses, strain force, total force, external spring data, beam deflections, individual energy terms, and stress data). In addition, a print and plot summary of all or part of the above noted data can be obtained at the end of the run by exercising plot control cards. Obviously, there is no need to print data at each time interval as well as at the end of the run. More likely, after initial checkout of the math model the user will find summary prints and plots of selected data more efficient and useful.

4.2 AIRPLANE AND/OR IMPACT SYMMETRY AND INITIAL CONDITIONS

The user of KRASH is required to input data for either a complete vehicle or only one-half of the vehicle. If the crash analysis involves symmetrical impact conditions (i.e., no roll, yaw or side motion), the user can simplify the input requirements and save nearly 40 percent in computer time by utilizing the symmetrical modeling capability of KRASH. The input symbol for controlling symmetrical or unsymmetrical coding in KRASH is the flag RUNMOD.

RUNMOD = 0 Full vehicle data required. Program analysis is valid for symmetrical or unsymmetrical impact conditions.

RUNMOD = 1 Half vehicle data required. Program analysis is valid for symmetrical conditions only.

RUNMOD = 2 Half vehicle data required. Program generates a full model and program analysis is valid for symmetrical or unsymmetrical crash conditions.

If the airplane itself is unsymmetrical, the user must input data for a complete airplane. For future consideration, a logical extension of KRASH capability would be to allow the program to calculate a full, symmetrical airplane model based on the half airplane input data, and punch cards for the full airplane model. The user can use these cards as a starting point for the full, unsymmetrical airplane model.

The input data required to define the impact condition are:

- longitudinal, lateral and vertical velocities (x,y,z) - in/sec
- roll, pitch, and yaw angular rates (p,q,r) - rad/sec
- roll, pitch and yaw angles (ϕ,θ,ψ) - radians

The data are in ground axes and the following directions apply:

- x,y,z are positive forward, out the right wing, and down, respectively
- p,q,r are positive right wing down, nose up, and tail left, respectively
- ϕ,θ,ψ are positive right wind down, nose up, and tail left, respectively

4.3 MASS COORDINATES AND PROPERTIES

A mathematical model developed for KRASH consists of a series of mass-concentrated nodes interconnected by massless members. The nodes are generally selected at locations where major masses are located and/or where significant forces are expected to act, such as at joints between major structural members. Typical of the points at which mass-concentrated nodes are located are the engine cg, selected wing stations, intersection of fuselage - vertical and horizontal tail, door or cabin section corners, fire wall, landing gear, seat, and occupant cg. Typically one should be able to model probable crash conditions

with less than 50 masses and preferably with between 30 and 40 masses, depending on the size of the vehicle. Since the members connecting the various nodes are considered massless, their actual weight and inertia properties are distributed among adjoining node points. Most structures that are represented in KRASH require such a distribution. Some distinct concentrated weight items such as engines, main gears, and occupants have well defined mass locations and properties. Panel point mass and inertia data frequently used in flutter analyses provide an excellent source of information from which the user can determine the necessary mass distributions.

The distribution of mass and inertia properties for the math model should reasonably approximate the vehicle's weight, cg location and mass inertial properties. These data should be obtainable within 5 percent of the actual values. However, the user should avoid placement of nodes resulting in light, stiff structure which gives rise to a high natural frequency. This could create stability problems which are discussed later in this section. The use of massless node points, also discussed in a later subsection, should facilitate the generation of a more detailed model thus minimizing stability problems. This implies that KRASH should not be expected to be an effective analytical tool for accurately predicting the motion of localized structure, or the local instability of a panel, frame, or shell. However, the larger the section of structure that is represented between nodes, the more effective KRASH can be as an analytical tool because of the techniques that are employed in the program.

KRASH employs essentially a lumped-mass analysis. The manner in which the masses and inertias are determined and assigned to the respective nodes is described in the following paragraphs. To obtain mass property estimates the user should first divide the vehicle into volume configurations. The use of simple geometric shapes is recommended as a first approximation. Reference 2 (Table 11) provides data regarding properties of plane areas. These data can be used to make estimates of mass properties of sections.

Typical of the shapes that are recommended are rectangular, parallelopipeds, right rectangular pyramids, right circular cones, and right elliptical cylinders. Figure 4-1 shows some of these shapes along with the volume,

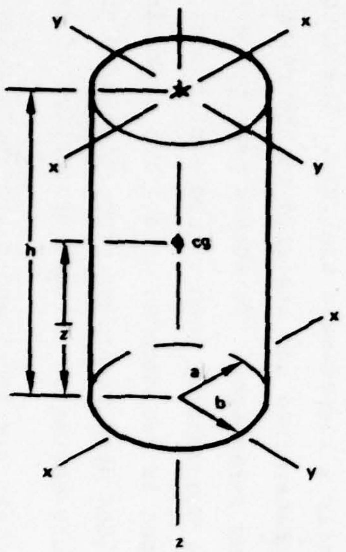
SOLID	VOLUME SURFACE AREA	CENTER OF GRAVITY	MOMENT OF INERTIA
1. Right Circular Cylinder 	$r = a = b$ $V = \pi r^2 h$ $S = 2\pi r(r + h)$	$\bar{x} = 0$ $\bar{y} = 0$ $z = \frac{h}{2}$	$I_x = I_y = \frac{M}{12}(3r^2 + 4h^2)$ $I'_z = \frac{M}{2} r^2$ $I'_x = I'_y = \frac{M}{12}(3r^2 + h^2)$
2. Right Elliptical Cylinder	$V = \pi abh$ $S = 2\pi ab + ph$ $p = \pi(a+b)\left[1 + \frac{k^2}{4} + \frac{k^4}{64} + \frac{k^6}{256} + \ldots\right]$ $k = \frac{a-b}{a+b}$	$\bar{x} = 0$ $\bar{y} = 0$ $\bar{z} = \frac{h}{2}$	$I_x = \frac{M}{12}(3b^2 + 4h^2)$ $I_y = \frac{M}{12}(3a^2 + 4h^2)$ $I_z = \frac{M}{4}(a^2 + b^2)$ $I'_x = \frac{M}{12}(3b^2 + h^2)$ $I'_y = \frac{M}{12}(3a^2 + h^2)$

Figure 4-1. Typical Sections and Properties (Reference 2) (Sheet 1 of 4)

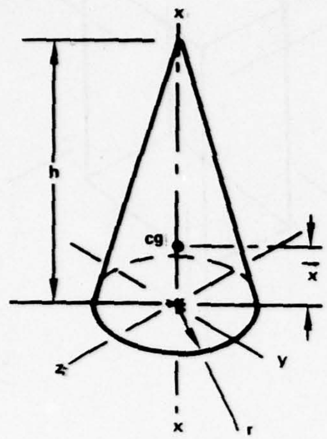
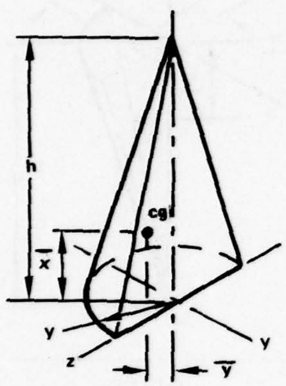
SOLID	VOLUME SURFACE AREA	CENTER OF GRAVITY	MOMENT OF INERTIA
3. Right Circular Cone 	$V = \frac{1}{3}\pi r^2 h$ $S = \pi r\left(r + \sqrt{r^2 + h^2}\right)$	$\bar{z} = 0$ $\bar{y} = 0$ $\bar{x} = \frac{h}{4}$	$I_z = I_y = \frac{M}{20}(3r^2 + 2h^2)$ $I_x = \frac{3M}{10} r^2$ $I'_z = I'_y = \frac{M}{80}(12r^2 + 3h^2)$
4. 	$V = \frac{1}{6}\pi r^2 h$ $S = \frac{1}{2}\pi r\left(r + \sqrt{h^2 + r^2}\right) + rh$	$\bar{z} = 0$ $\bar{y} = \frac{r}{\pi}$ $\bar{x} = \frac{h}{4}$	$I_z = I_y = \frac{M}{20}(3r^2 + 2h^2)$ $I_x = \frac{3M}{10} r^2$ $I'_z = \frac{M}{80\pi^2}\left[4(3\pi^2 - 20)r^2 + 3\pi^2 h^2\right]$ $I'_y = \frac{M}{80}(12r^2 + 3h^2)$

Figure 4-1. Typical Sections and Properties (Reference 2) (Sheet 2 of 4)

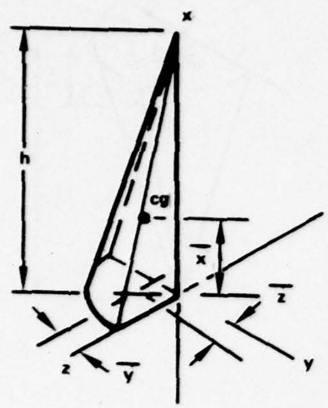
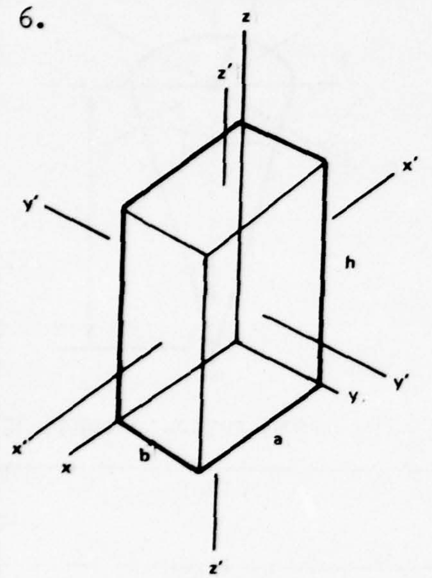
SOLID	VOLUME SURFACE AREA	CENTER OF GRAVITY	MOMENT OF INERTIA
5. 	$V = \frac{1}{12} \pi r^2 h$ $S = \frac{1}{4} \pi r \left(r + \sqrt{h^2 + r^2}\right) + rh$	$\overline{z} = \frac{r}{\pi}$ $\overline{y} = \frac{r}{\pi}$ $\overline{x} = \frac{h}{4}$	$I_z = I_y = \frac{M}{20} (3r^2 + 2h^2)$ $I_x = \frac{3M}{10} r^2$ $I'_z = I'_y = \frac{M}{80\pi^2} \left[4(3\pi^2 - 20)r^2 + 3\pi^2 h^2\right]$
6. 	$V = abh$ $S = 2(ab + ah + bh)$	$\overline{x} = \frac{a}{2}$ $\overline{y} = \frac{b}{2}$ $\overline{z} = \frac{h}{2}$	$I_x = \frac{M}{3} (b^2 + h^2)$ $I_y = \frac{M}{3} (a^2 + h^2)$ $I_z = \frac{M}{3} (a^2 + b^2)$ $I'_x = \frac{M}{12} (b^2 + h^2)$ $I'_y = \frac{M}{12} (a^2 + h^2)$ $I'_z = \frac{M}{12} (a^2 + b^2)$

Figure 4-1. Typical Sections and Properties (Reference 2) (Sheet 3 of 4)

6. (Continued)

where

$I_{x,y,z}$ = Mass moment of inertia about x, y and z axis $lb - in - sec^2$

$I_{x',y',z'}$ = Mass moment of inertia about x',y' and z' axis (Center of Gravity)

M = Mass, $lb/in/sec^2$

a,b,h = Side dimensions, in

S = Surface area, in^2

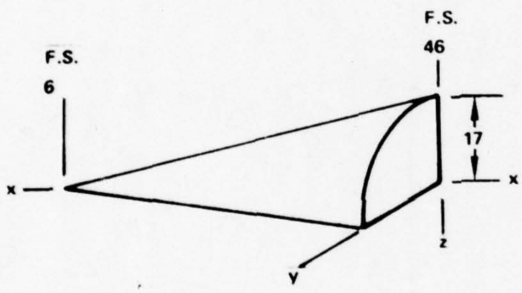
V = Volume, in^3

Figure 4-1. Typical Sections and Properties (Reference 2) (Sheet 4 of 4)

surface area, center of gravity, and mass moment of inertia associated with the sections. As a first approximation, the distribution of the mass within the volume is assumed such that the center of gravity of the volume coincides with the location of the mass nodal mass point. Having volumes which overlap or extend beyond the vehicle surface is acceptable although some minor inaccuracies will result. Figure 4-2 shows a section of an airplane. Using typical sections from Reference 2 and Figure 4-1, sample calculations of mass properties are shown as follows:

Sample Calculations:

Mass Location 2 (Quarter section of Right Circular Cone, No. 5 Figure 4-1)



w = 3.1 lb.
r = 17 in.
h = 40 in.

$$I_x' = \frac{3w}{10(386)} r^2 = .696$$

$$I_y' = I_z' = \frac{w}{(80)(386)\pi^2}\left[4(3\pi^2 - 20)r^2 + 3\pi^2 h^2\right] = .595$$

These calculations apply to a solid body of homogeneous mass distribution. Frequently airplane structure is made up of more nearly hollow sections of cylinders and cones. For these sections, the inertias can be calculated by subtracting the inertias of the inner volume from those of the outer volume. In many cases, the only difference between these is the skin thickness.

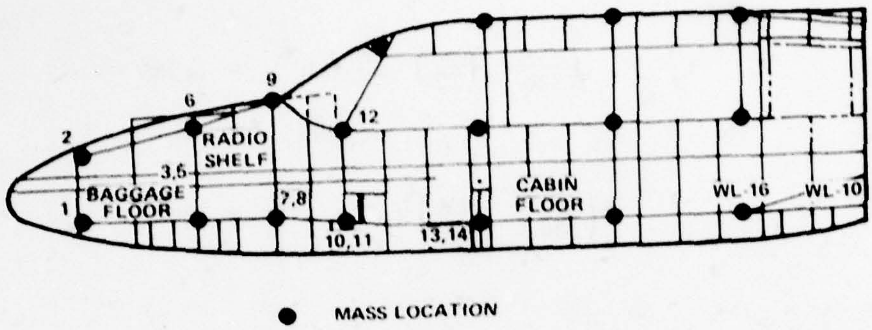
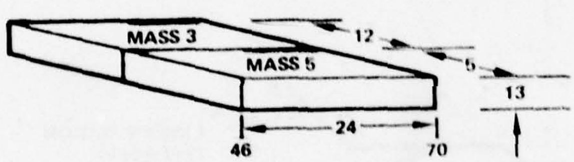


Figure 4-2. Airplane Section Showing Mass Locations

Mass Locations 3, 5 (Rectangular Section, No. 6 Figure 4-1)

Mass 3; w = 6 lb
a = 24
b = 12
h = 13



$$I_{x'} = \frac{1}{386}\left(\frac{w}{12}\right)\left(h^2 + b^2\right) = .405$$

$$I_{y'} = \frac{1}{386}\left(\frac{w}{12}\right)\left(a^2 + h^2\right) = .965$$

$$I_{z'} = \frac{1}{386}\left(\frac{w}{12}\right)\left(a^2 + b^2\right) = .933$$

Mass 5; w = 6 lb
a = 24
b = 5
h = 13

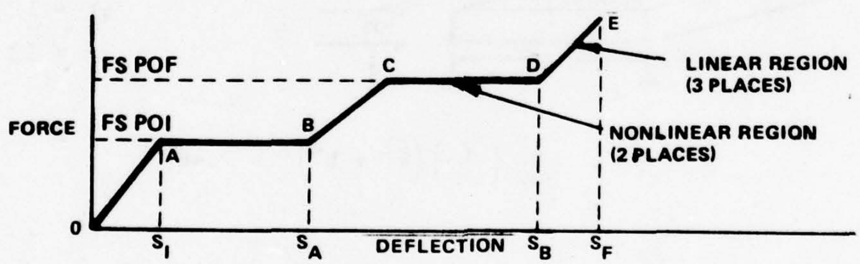
$$I_x' = \left(\frac{1}{386}\right)\left(\frac{W}{12}\right)(h^2 + b^2) = .251$$

$$I_y' = \left(\frac{1}{386}\right)\left(\frac{W}{12}\right)(a^2 + h^2) = .965$$

$$I_z' = \left(\frac{1}{386}\right)\left(\frac{W}{12}\right)(a^2 + b^2) = .778$$

4.4 EXTERNAL SPRINGS

External springs are used to simulate the deformation of crushable structure by the ground. The external spring can define a combination of linear and nonlinear behavior. It is limited to defining a maximum of three linear regions (DA, BC, DE) and two nonlinear (AB, CD) as noted in the general load-deflection curve shown below:



In KRASH, two sets of data are required to define the external springs. One set of data defines the mass, the direction, the coefficient of friction, the extended length, bottoming stiffness and the associated plowing force and ground flexibility (for soil impacts only) for each spring. The second set of data describes the load-deflection characteristics which requires input data for S_1, S_A, S_B, S_F, FSPOI and FSPOF as defined in the sketch above.

Characteristically, the deformation of crushable structure or deformed terrain is such that a region is reached wherein the confined crushing that takes place is very significant and the stiffness substantially increases. The final linear region in the sketch above represents this region.

The application of external springs to describe crushable regions is best illustrated using the following two examples, one based on test results (Reference 3) and the other on analysis (Reference 4). Figures 4-3(a) and 4-3(b) show a segment of a structure before and after a crush test. The segment is approximately 26 inches high, 50 inches long and 11 inches wide. The load-deflection and associated energy absorbed curves are shown in Figure 4-4. Also shown in Figure 4-4 is the representation of the structure's load-deflection and energy absorption characteristics used in KRASH. The structure shown in Figure 4-5(a) and 4-5(b) represents a substructure for which the load-deflection characteristics were obtained by analysis and verified by test. The structure, whose overall dimensions were half size (46 inches long, 12 inches wide, and 6 inches deep), represents a portion of a large section of a helicopter as can be noted in Figure 4-6. The analytically obtained load-deflection curve is shown in Figure 4-7, along with the characteristics of the external spring used in KRASH to represent the structure's load-deflection behavior.

The two examples point out that an external spring represents gross behavior of a reasonably large section of structure, and approximates the behavior of the structure with a load-deflection curve which defines the peak load and energy absorption characteristics with reasonable accuracy.

When the effects of two different stiffness characteristics in series are involved then a combined load-deflection curve which is a function of both stiffnesses is developed. Figure 4-8 illustrates how two different external spring load-deflection curves in series are combined for KRASH. The dashed curve is the composite of curves 1 and 2. For the case shown, the external spring representing the crushable region is depicted by two linear regions and one nonlinear region.

Determining the load-deflection characteristics of structure can be involved if test data is not available. Some guidelines for determining this data is provided in Section 4.10.5.

Once the input requirements have been satisfied it is important to understand how the external spring forces are used in KRASH. This aspect of

(a) Pretest Condition

(b) Post Test Condition

Figure 4-3. Pretest and Post Test Condition of a Fuselage Bumper Substructure (Reference 3)

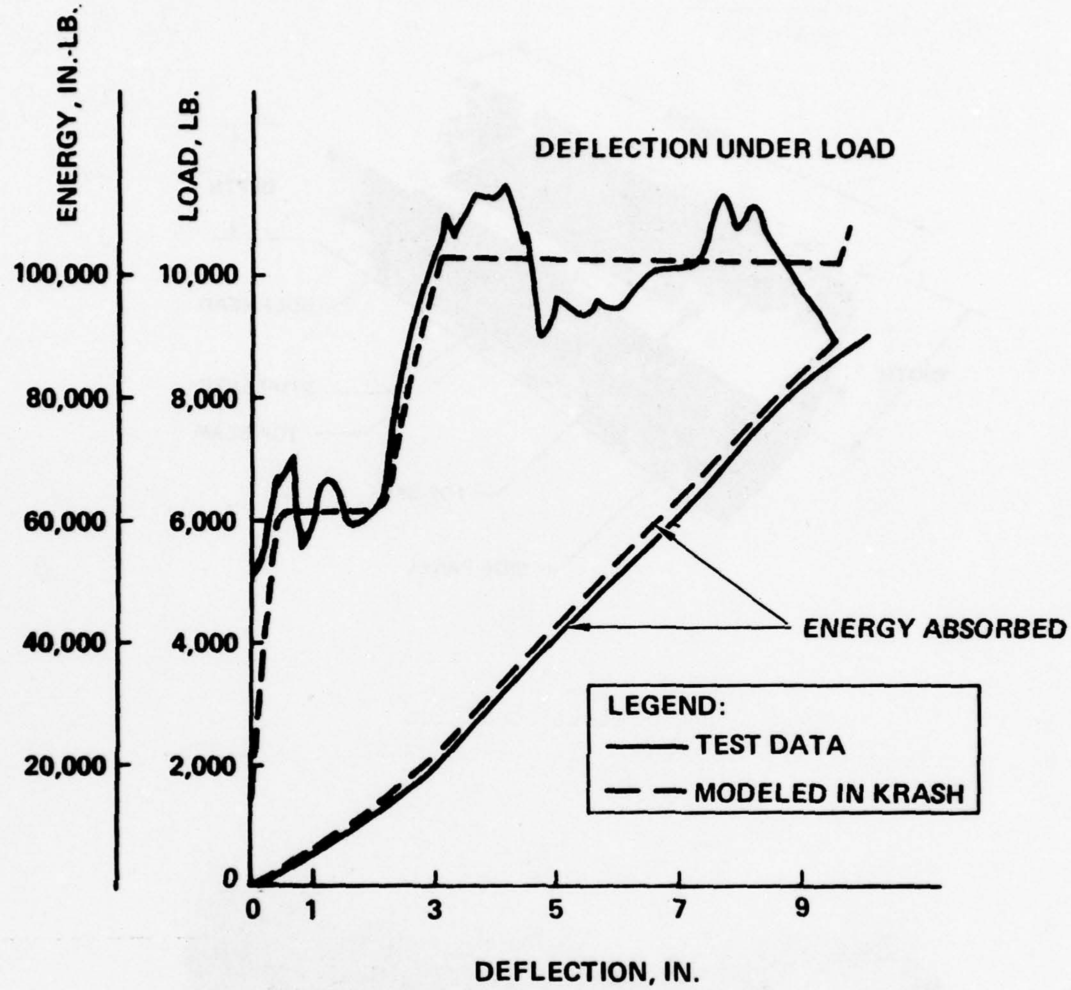
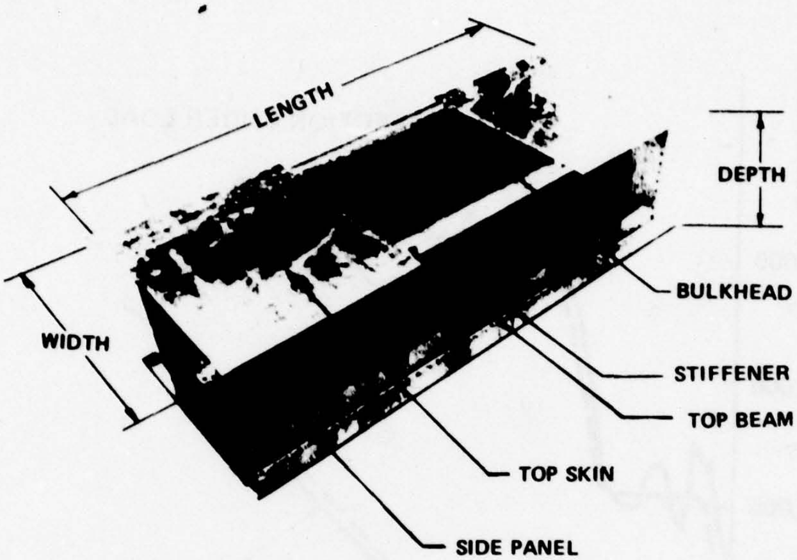


Figure 4-4. Load-Deflection and Energy Absorption Characteristics for the Fuselage Bumper Substructure (Reference 3)

KRASH is important not only in setting up a model but in evaluating results with regard to their validity, as well as to determining possible changes that may be required. As described in Reference 1, external springs can extend in any or all of three directions (k = 1,2,3). The k = 1 direction represents a spring acting along the longitudinal axis, the k = 2 direction represents a lateral spring and the k = 3 direction represents a vertical spring. The lengths of the springs are input positive or negative; positive springs point forward, right and down relative to the airplane, negative



(a) Pretest Condition

(b) **Post Test Condition**

Figure 4-5. Pretest and Post Test Condition of a 12-Inch Deep Lower Fuselage Substructure Specimen (Reference 4)

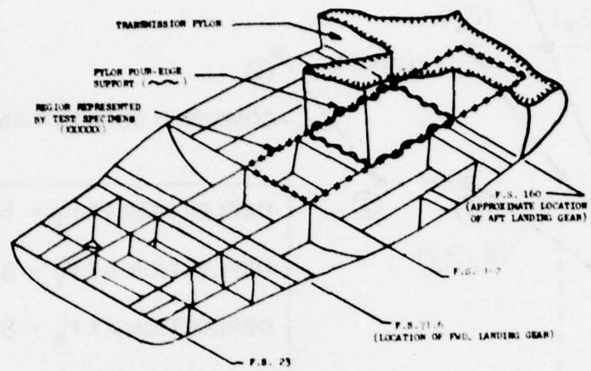


Figure 4-6. Location of Substructure in Lower Fuselage of Helicopter (Reference 4)

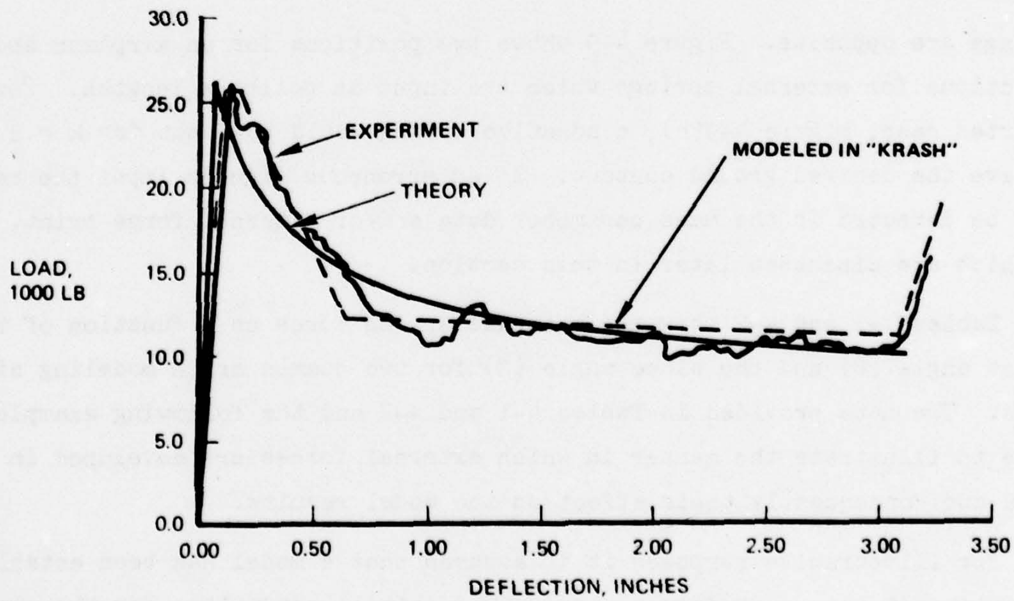


Figure 4-7. Load-Deflection Curve for Substructure and Corresponding Math Model Representative Curve (Reference 4)

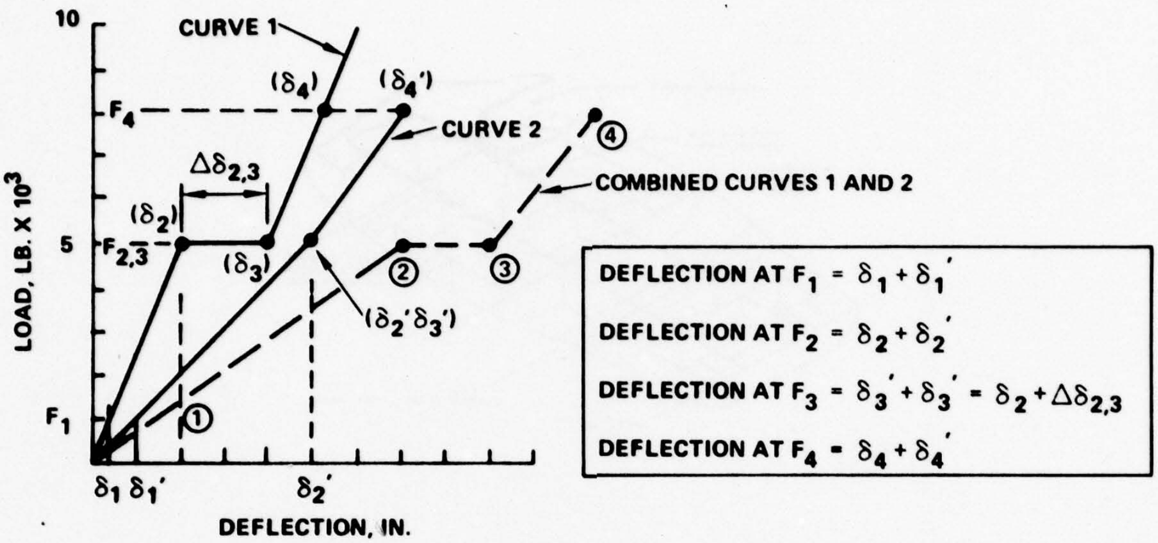
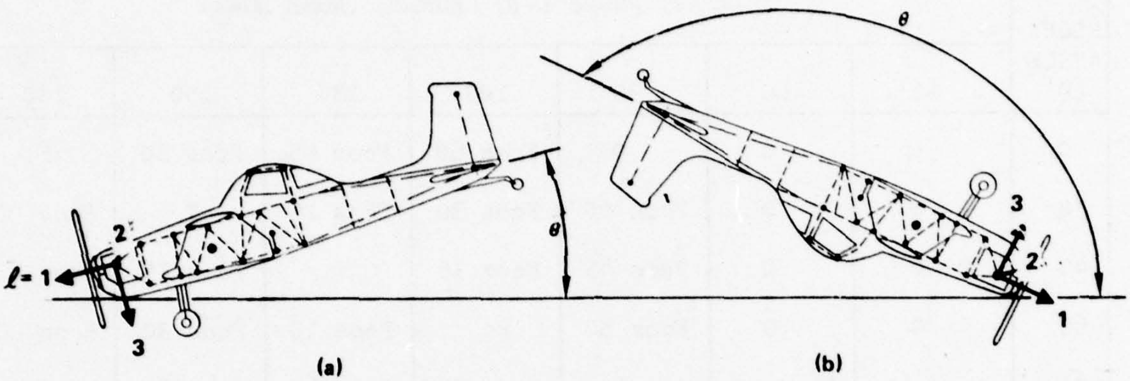


Figure 4-8. Combined Load-Deflection Characteristics Modeled in KRASH

springs are opposite. Figure 4-9 shows two positions for an airplane and the directions for external springs which are input as positive lengths. For the inverted case, Figure 4-9(b), a negative spring would be input for $k = 3$ to achieve the desired ground contact. If an erroneous sign is input the results will be detected in the mass parameter data and/or external force print, both of which are discussed later in this section.

Tables 4-1 and 4-2 show the external spring force as a function of the impact angle (θ) and the slope angle (β) for two common crash modeling situations. The data provided in Tables 4-1 and 4-2 and the following example serve to illustrate the manner in which external forces are developed in KRASH and consequently their effect on the model results.

For illustrative purposes it is assumed that a model has been established for an impact into a 90-degree slope. The initial conditions for the airplane are:



NOTE: θ SHOWN IS INPUT AS NEGATIVE TO KRASH

ℓ = 1 LONGITUDINAL DIRECTION
ℓ = 2 LATERAL DIRECTION
ℓ = 3 VERTICAL DIRECTION

Figure 4-9. External Spring Positive Length Directions

TABLE 4-1. EXTERNAL SPRING FORCE NORMAL TO THE SLOPE FOR $\ell = 1$ DIRECTION, POSITIVE LENGTHS

SLOPE ANGLE (β)	IMPACT ANGLE ($-\theta$) DEGREES (NOSE DOWN)				
	0	30 (150)	45 (135)	60 (120)	90
0	0	Fcos 60	Fcos 45	Fcos 30	F
30	Fsin 30	Fcos 30	Fcos 15	F	Fcos 30
45	Fsin 45	Fcos 15	F	Fcos 15	Fcos 45
60	Fsin 60	F	Fcos 15	Fcos 30	Fcos 60
90	F	Fcos 30	Fcos 45	Fcos 60	0

(a) F = External Spring Force (Function of Spring Compression)

(b) Force along the slope equals the coefficient of function (μ) times the force normal to the slope

TABLE 4-2. EXTERNAL SPRING FORCE NORMAL TO THE SLOPE FOR ℓ = 3 DIRECTION, NEGATIVE LENGTHS

SLOPE ANGLE (β)	IMPACT ANGLE ($-\theta$) DEGREES (NOSE DOWN)						
	45	60	90	120	135	150	180
0	0	0	0	Fcos 60	Fcos 45	Fcos 30	F
30	0	0	Fcos 60	Fcos 30	Fcos 15	F	Fcos 30
45	0	0	Fcos 45	Fcos 15	F	Fcos 15	Fcos 45
60	0	0	Fcos 30	F	Fcos 15	Fcos 30	Fcos 60
90	Fcos 45	Fcos 30	F	Fcos 30	Fcos 45	Fcos 60	0

(a) No ground contact for $\theta < 45$

(b) F = External Spring Force (Function of Spring Compression)

(c) Force along the slope equals the coefficient of friction (μ) times force normal to the slope

longitudinal cg velocity ($\dot{x}$) = 259 in/sec
vertical cg velocity ($\dot{z}$) = 19.5 in/sec
pitch attitude (θ) = -38.5 degrees (nose down)
pitch rate ($\dot{\theta}$) = 105 deg/sec nose down
ground coefficient (μ) = 1.0

The impact situation and external spring load-deflection curve are depicted in Figure 4-10.

From mass 11 external springs extend in the airplane longitudinal and normal directions. These are identified in Figure 4-10 as 11-1 and 11-3, respectively. The airplane velocity at the time of contact with the surface, point O, is determined from the initial cg translation velocity and rotational velocity components as shown in Figure 4-11. They result in the velocities at point O acting in the forward and down directions. Consequently, the reaction force (F_N) is normal to the surface and the drag component (F_d) is

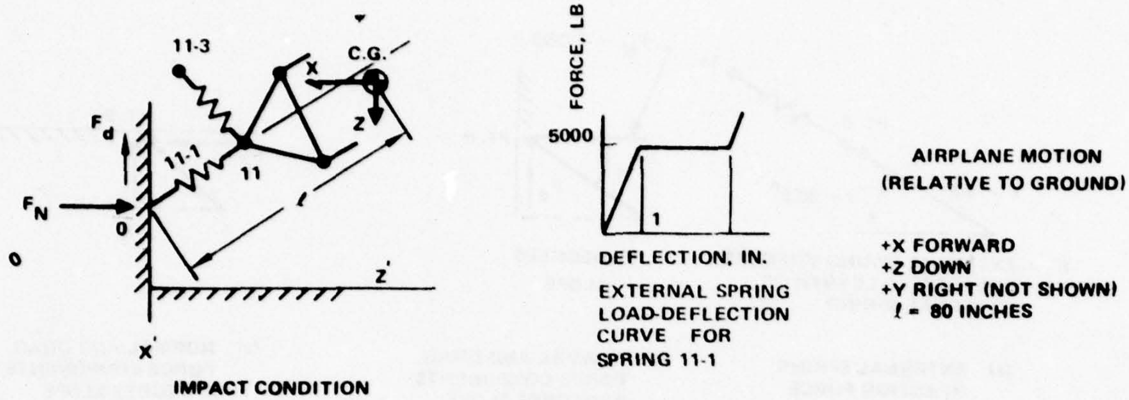


Figure 4-10. Typical Impact Condition

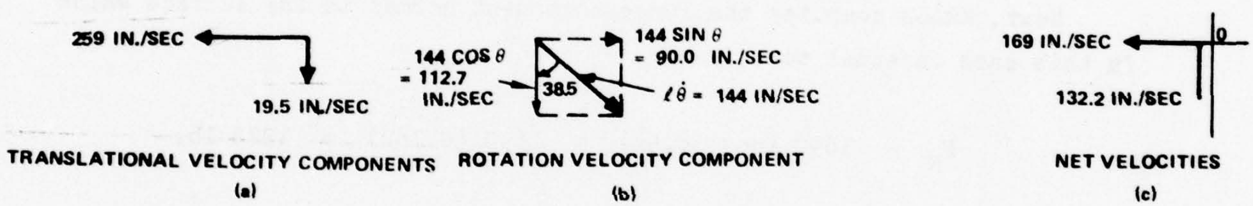


Figure 4-11. Spring Contact Point Velocity

upward as shown in Figure 4-12. To determine the magnitude of the normal and drag forces that are acting, one has to understand that KRASH treats the slope angle and attitude of the airplane in the following manner.

- The spring force (F) acting along the direction of the spring is computed initially. This force is shown in Figure 4-12.

- The force components normal and parallel (F_n and F_d) to the contact surface (slope) are computed. F_d acts opposite the direction of the corresponding velocity component. These force components are shown for a 90 degree and 0 degree slope in Figure 4-12.

Assume one is interested in the forces acting shortly after impact (0.002 seconds). The deflection of the external spring can be estimated from $\Delta x = (\dot{x})(\Delta t) = 169 \times 0.002 = 0.338$ inches. From the load deflection curve, the force at t = 0.002 can be obtained from $(K)(\Delta X) = 5000 \times 0.338 = 1690$ lb.

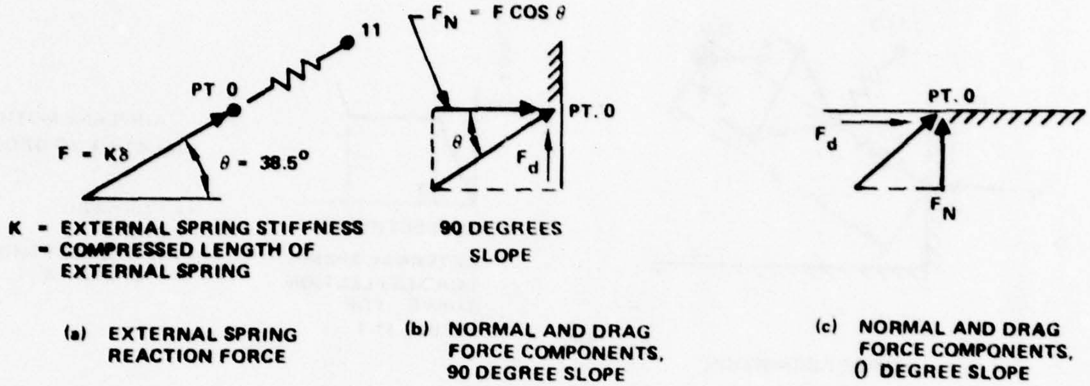


Figure 4-12. Normal and Drag External Spring Force Components

Next, KRASH computes the force component normal to the surface which in this case is equal to

$$F_N = 1690\,(\cos 38.5^\circ) = 1690\,(0.782) = 1323 \text{ lb.} \tag{4-1}$$

The drag force parallel to the surface is then obtained from

$$F_d = \mu F_N = 1.0\,(1323) = 1323 \tag{4-2}$$

Following the procedures above one can estimate the reaction force components for external springs acting on the appropriate masses for different directions, attitudes, coefficients of friction, slope angles and initial velocities. Obviously as more springs are involved and as time progresses in the crash analysis, the results are more tedious to evaluate. However, at any cut in time each external spring can be isolated, and knowing the load-deflection curve and KRASH output data one can verify the results. Figure 4-13 presents the portion of the output that pertains to external spring data for the crash condition described above. As can be noted, the

EXTERNAL SPRINGS

MASS I	SPRING K	SPRING COMPRESSION	SPRING COMPRESSION LOAD	GROUND CONTACT POINT LOADS IN GROUND OR SLOPE AXES X(+ AFT OR DOWN SLOPE)	Y(+ LEFT)	Z(+ UP OR NORMAL TO SLOPE)	GROUND CONTACT POINT LOADS IN MASS AXES X (+ FORWARD)	Y (+ RIGHT)	Z (+ DOWN)
11	1	4.380490 00	4.000000 03	-3.046720 03	0.0	3.048720 03	-4.297310 03	0.0	-3.500470 02
11	3	1.610180 00	4.000000 03	-2.589450 03	0.0	2.589450 03	-3.649950 03	0.0	-2.973150 02

Figure 4-13. External Spring Output

output shows the mass identification and direction of the spring as well as its compression and the forces acting at the contact surface in both ground and mass axes. Given this data and knowing the model geometry, the forces and moments that act on the appropriate mass for the respective external springs can be determined. The information described in this subsection is also important in that one can evaluate whether the model setup, given the initial conditions, is proper for the situation being analyzed. For example, in a turnover it is important to know the line of action of the forces and the force magnitudes in order to determine the manner in which the airplane will rotate after impact.

4.5 INTERNAL LINEAR AND NONLINEAR STRUCTURAL MEMBERS

Program KRASH describes the interaction between a series of massless interconnecting structural elements and concentrated rigid body masses to which the structural elements are attached at their ends. The interconnecting elements represent the stiffness characteristics of the structure between the masses. The masses can translate and rotate in all directions under the influence of the external forces (i.e., gravity, aerodynamics, impact) as well as the constraining internal forces. The manner in which the structure moves and the forces act, is directly related to the manner in which the structure being analyzed is modeled and the direction and magnitude of the external forces, as is the situation whenever real structure is idealized mathematically.

4.5.1 Linear Elements

Program KRASH requires that each internal structural element (those elements which are not in direct contact with an impact surface) be

represented by six load-deflection curves. Depending on the direction of the loading and the manner in which the structural elements attach to one another, some of the six load-deflection curves may not be significant and consequently will not require as accurate a representation as the others. The six directions define bending in two planes, torsion and axial loads. Program KRASH accepts as input data for each internal element the following data:

A = cross sectional area, in^2
J_x = torsional stiffness factor, in^4
I_y = moment of inertia about element y axis, in^4
I_z = moment of inertia about element z axis, in^4
XIQ = torsional shape factor (XIQ · moment = stress, Ref 5)
Z1 = distance from neutral axis about y axis to extreme fiber, in
Z2 = distance from neutral axis about z axis to extreme fiber, in
MC = material code

Wherein $J_x = I_y + I_z$, the user can input zero for J_x and KRASH will sum $I_y + I_z$.

Currently KRASH contains data for six standard materials (MC = 1 - 6) and four material codes (MC 7-10) to give added modeling flexibility. The user can also specify any nonstandard material property (MC 16-20) as described in Section 2.1.

For each material there is specified:

E = modulus of elasticity, psi
G = modulus of rigidity, psi
σ_c = allowable compression stress, psi
σ_t = allowable tension
σ_s = allowable shear stress, psi

The properties of the various materials are shown in Table 4-3. In addition to the above data KRASH allows the user to specify if the beam is pinned-fixed or pinned-pinned. Unless the end condition is noted all beams are considered fixed-fixed.

TABLE 4-3. MATERIAL PROPERTIES

MAT'L CODE	MATERIAL	MODULUS OF ELASTICITY E X 10^{-6} (lb/in^2)	SHEAR MODULUS OF ELASTICITY G X 10^{-6} (lb/in^2)	TENSILE YIELD STRESS σ_t (lb/in^2)	COMPRESSIVE YIELD STRESS σ_c (lb/in^2)	SHEAR YIELD STRESS σ_s (lb/in^2)
1	4130 Steel	30	11	75000	75000	37500
2	6150 Steel	30	11	205000	205000	80000
3	300 Series Stainless Steel	28	12.5	70000	46000	36000
4	2024-T3 Al.	10.5	4	47000	39000	22000
5	6061-T3 Al.	10	3.8	35000	34000	17000
6	B195-T4 Cast Aluminum	10	3.8	16000	16000	17000
7	Low Modulus Mat'l	1	0.3	16000	16000	17000
8	Zero-Torsion Mat'l	1	0	16000	16000	17000
9	DRI Spine (MAN)	1	0.3	16000	16000	17000
10	DRI Spine (DRI)	1	0.3	16000	16000	17000

The stiffness matrix, whether obtained by direct input or internally computed, is linear and remains so for each element unless the element is specified to have nonlinear characteristics. The linear stiffnesses for the various elements can be obtained from test data or from analysis. For example, during the normal course of certifying an aircraft, static tests are performed in which loads and moments at various fuselage stations are obtained for a specified condition. Data obtained from this source can be used to obtain the linear stiffness data required by KRASH. As an example, assume that the out-of-plane bending moments and deflections are obtained at two different stations and the available data is as noted below:

length = 81.4

deflection (pt. 1) = -1.40 inches

deflection (pt. 2) = +0.4 inches

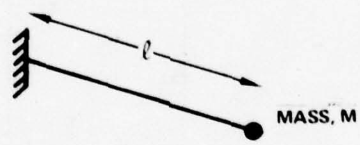
moment, Mx, varies linearly from 0 in-lb at point 1 to 60,580 in-lb at point 2

The relative deflection (Δ) is 1.44 inches. The EI_z product required for the out-of-plane stiffness terms is given by

$$EI_z = \int_1^2 \frac{Mxdx}{\Delta} = \frac{1.1416 \times 10^8}{1.44} = 0.79 \times 10^8 \qquad (4-4)$$

Knowing the material E, the average section area moment of inertia I_z can then be obtained.

Another approach to obtaining stiffnesses from test data is to use natural frequency data. For example, for a strut-mounted mass or cantilevered mass the stiffnesses can be approximated from frequency data as follows:



$$\omega_n = \sqrt{K/M}$$

$$Kz_{eff} = M\omega_n^2$$

where

ω_n = natural frequency, rad/sec

M = mass at end plus 1/2 of member mass

With the structural material and member length known, the area inertia can be obtained from the expression

$$Kz_{eff} = \frac{3EI_y}{\ell^3} \quad (4\text{-}5)$$

and therefore

$$I_y = \frac{M\omega_n^2 \ell^3}{3E} \quad (4\text{-}6)$$

For tubular structure, $I_y = I_z$. For elements with a variable cross section the average I_y and I_z properties can be determined. The use of average section properties is applicable to landing gear, engine mount and wing structure. Generally speaking, average cross-sectional properties I_y, I_z, A are available for these structures, and thus the stiffness terms can be readily determined.

In developing input data for the element linear stifnesses, it is important that the user follow the notations that KRASH has established for beam orientations. These orientations and the respective x, y, z coordinates are shown in Figure 4-14.

The information in Figure 4-14 is used as illustrated below. Assuming an internal element is oriented in the fore-aft direction from mass number 1 (forward) to 10 (aft), the beam axes are defined as:

+y to the left

+z down

+x aft

If the same beam had been set up in the model with the mass numbers reversed, then the beam axes would have been defined as:

+y to the right

+z down

+x forward

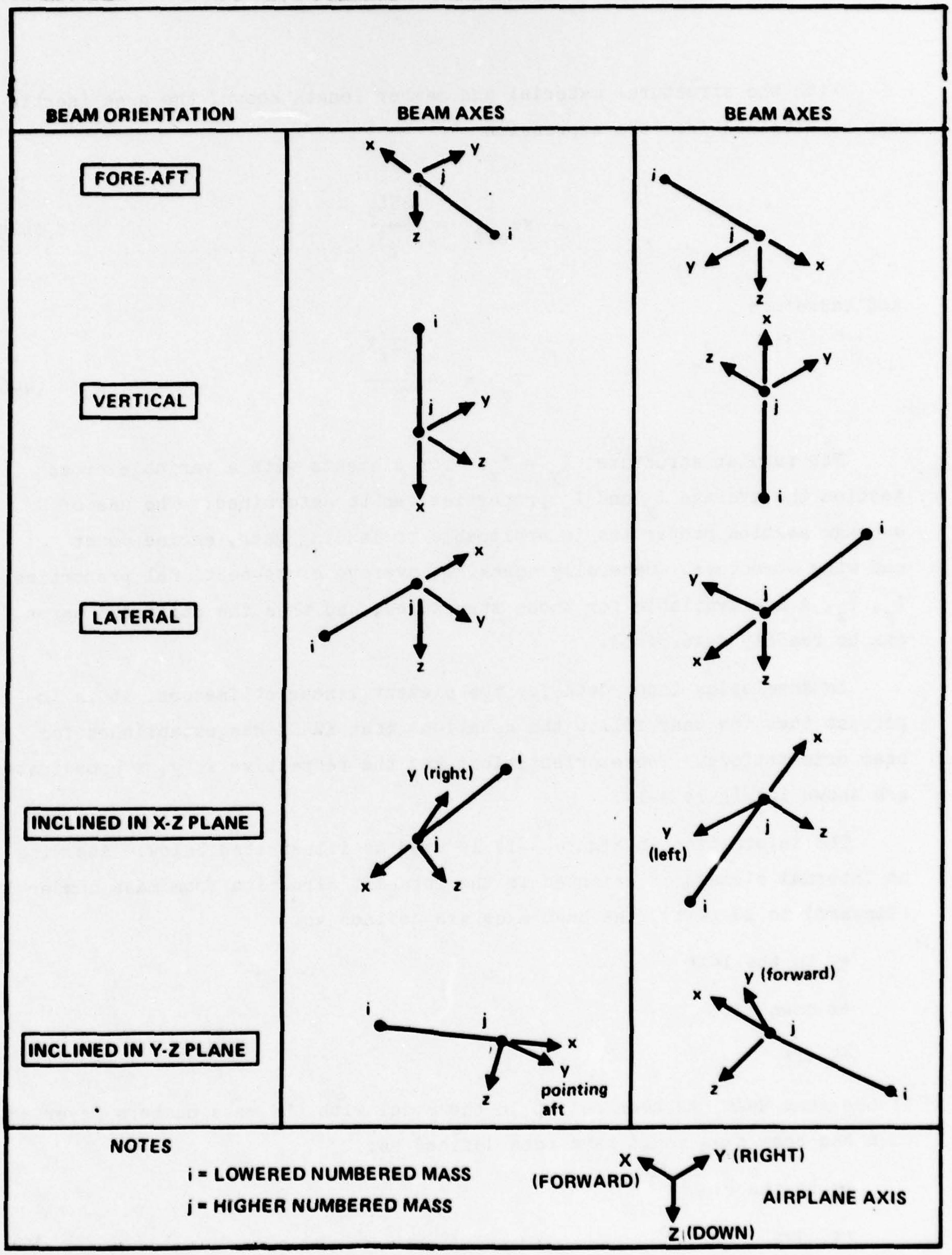


Figure 4-14. Beam Axes Orientation

Knowing the proper beam axes orientation is important since the element area moment of inertias have to be input about the y and z axes. As can be seen from Figure 4-14, the axis definition depends on the beam orientation. The user should calculate the element properties knowing that KRASH assigns the x, y, z axes for each beam based on its orientation relative to the airplane x, y, z axes. Also, knowing the orientation of each element is important in the interpretation of the member force and deflection output data.

4.5.2 Nonlinear Elements

Yield strength, plastic deformation, and postfailure behavior are accounted for in KRASH by the use of stiffness reduction factors (KR's). These factors modify the linear stiffness of each structural element to which they are applied. Since it is not usually necessary to consider all the elements as nonlinear, a particular problem may require that only 10 to 30 percent of of the structure be modified by KR factors. The internal forces (F_{ij}) for each element are computed as follows:

$$\left\{dF_{ij}\right\} = \left[KR_{ij}\right]\left\{dF_{ij}\right\}_{\text{linear}} \qquad (4\text{-}7)$$

$$\underset{\text{current}}{\left\{F'_{ij}\right\}} = \underset{\text{previous}}{\left\{F'_{ij}\right\}} + \underset{\text{incremental}}{\left\{dF'_{ij}\right\}} \qquad (4\text{-}8)$$

KR's can be thought of as a means of altering the stiffness properties of an element after it has reached yield. Given a linear stiffness matrix and an KR curve (KR versus deflection), one can obtain a force versus deflection curve by the following expression:

$$F_{ij\ell} = K_{ij\ell\ell}\int_{0}^{vb_{ij\ell}} KR_{ij\ell}\, dvb_{ij\ell} \qquad (4\text{-}9)$$

Subscripts ij refer to the beam connecting masses i and j. Subscript ℓ refers to the ℓ^{th} direction (x, y, z, ϕ, θ, or ψ). $K_{ij\ell\ell}$ is the ℓ^{th} diagonal term

in the stiffness matrix $[K_{ij}]$. This equation is valid only for the case wherein no coupling exists in the linear stiffness matrix. For example, this is normally the case for axial loading (x) and torsion (ϕ).

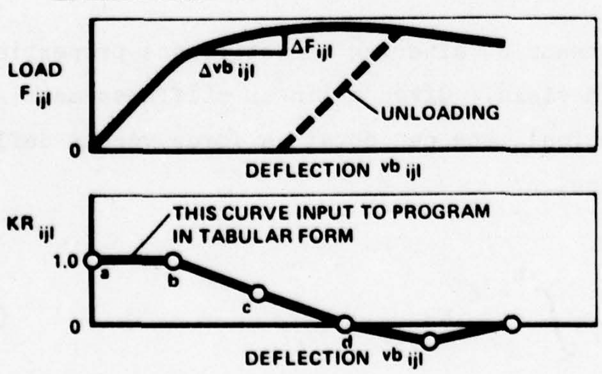
Figure 4-15 illustrates the relationship between a KR versus deflection curve and the corresponding load-deflection curve.

When KR = 1 the linear stiffness is unaltered, and the force-deflection curve is linear for the particular element. Consequently, the portion of the curve shown by a-b in Figure 4-15 represents a typical linear force-deflection curve. In the region from 'b' to 'c' (Figure 4-15), the KR term goes from 1 to 0. A KR = 0 reduces the stiffness to zero which results in a constant force at that time. Consequently, from 'b' to 'c' the incremental force changes as the integral of KR-dx as shown below:

$$\Delta F = K \int_b^c KR\, dx \qquad (4\text{-}10)$$

and the total force acting at point c is

$$F_c = F_b + \Delta F = (K\, v_b) + K \int_b^c KR\, dx \qquad (4\text{-}11)$$



ij = ijth ELEMENT, 1 TO NO. ELEMENT

SEE TABLE 4-4 FOR "ℓ" DESIGNATIONS

Figure 4-15. Relationship Between Force Versus Deflection and KR Versus Deflection Curve

Continuing the process from 'c' to 'd', KR goes negative which is the equivalent of a negative stiffness. If KR at 'd' were = -1, then the stiffness at 'd' would be -K. However, in the sample shown KR ≈ -0.1 and therefore the force at 'd' equals

$$F_d = F_c + K \int_c^d KR \, dx \tag{4-12}$$

The determination of the exact nonlinear behavior of structural elements is very difficult, particularly when interaction of loads is involved. It was shown in Reference 6 that by approximating the nonlinear behavior while presenting the proper failure load, responses which are sufficiently accurate for crash analysis purposes are obtained. KRASH carries this approach one step further by preprogramming some typical nonlinear curve shapes. The need to input KR tables is practically eliminated. Instead, the input data requirements for each nonlinear element are the number identification, the direction ($x, y, z, \phi, \theta, \psi$), the deflection at peak load, and type of curve (NP = number of points needed to describe the curve) as shown and described in Figure 4-16.

The NP = 5 through 8 curves describe post-failure characteristics for an individual element. The NP = 9 curve can be defined for structural behavior of elements which may act in series. The use of this type of curve is

TABLE 4-4. MEMBER FORCE AND DEFLECTION DESIGNATIONS

K	MEMBER FORCE DIRECTION	PROGRAM DESIGNATION	ℓ	MEMBER DEFLECTION DIRECTION	PROGRAM DESIGNATION
1	axial force	X	1	axial deflection	x
2	out-of plane force	Y	2	out-of-plane deflection	y
3	in-plane force	Z	3	in-plane deflection	z
4	torsional moment	M	4	rotation about x axis	ϕ
5	in-plane moment	N	5	in-plane rotation	θ
6	out-of plane moment	L	6	out-plane rotation	ψ

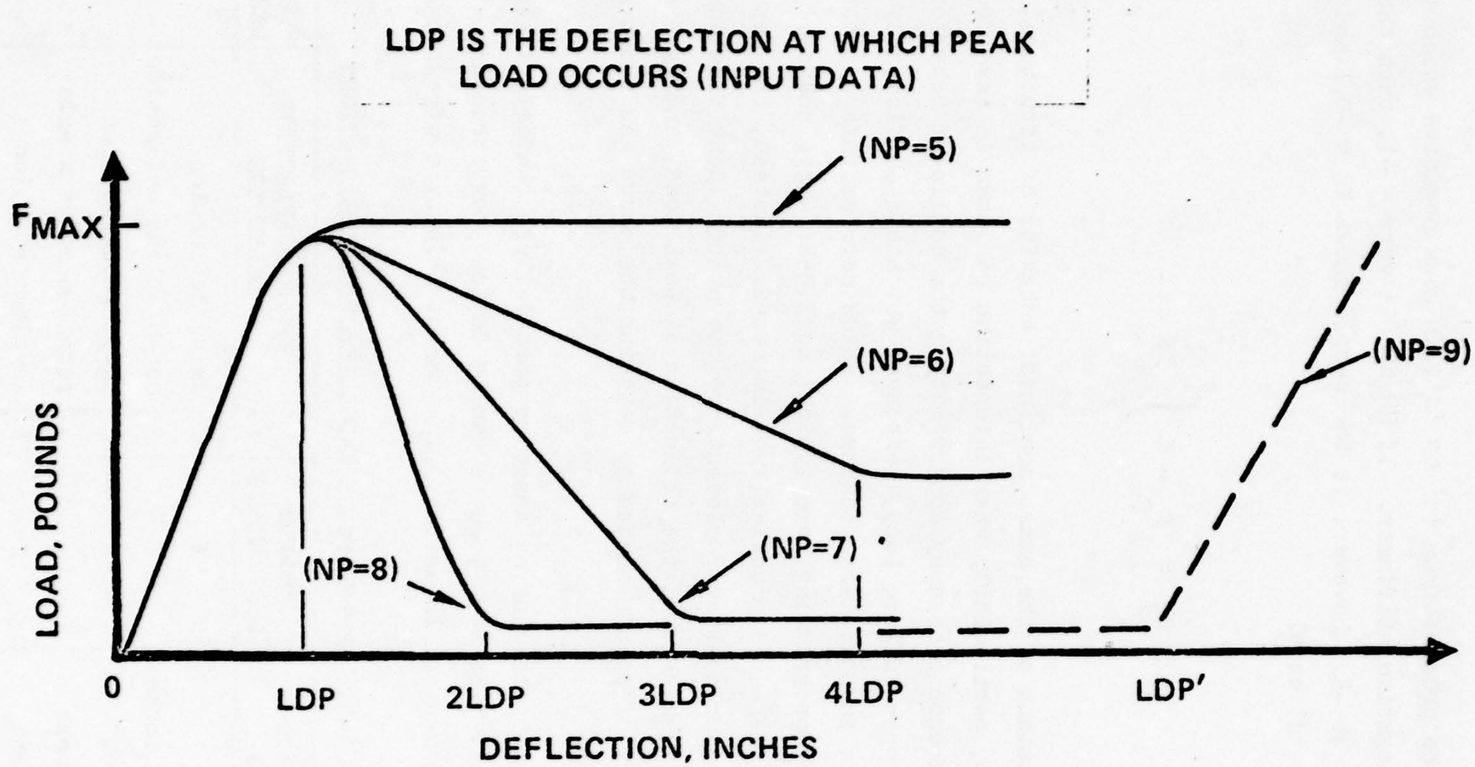


Figure 4-16. Standard Nonlinear Load-Deflection Curves Contained in KRASH

desirable to describe the collapse of one structure wherein the load then is transmitted to a stiffer member (i.e., engine support mount attached to fire-wall or bulkhead). KRASH allows the user to model this type of structure by defining a curve as having nine points (NP = 9), and providing the same member identification, direction and failure deflection information required of NP = 5, 6, 7, and 8 curves, plus the deflection at which restiffening occurs.

The user is not restricted to using internally-coded nonlinear curves. The user can define any shape by inputting a value of NP equal to or greater than 10 but no more than 15. For this particular type of curve, the user specifies a table of KR vs deflection, as described in Section 2.1.

To help the user take full advantage of KR-deflection curves, the non-dimensional plot, shown in Figure 4-17, and the KR-deflection data for internally coded nonlinear curves, shown in Table 4-5, are presented. For values of $P \leq 1.0$ and $X \leq 1$ (Figure 4-17), the load-deflection values correspond to the linear stiffness (KR = 1) for the appropriate member and its direction. At $X > 1$ the load-deflection characteristics are nonlinear and KR factors modify the linear stiffness. From the data provided in Figure 4-17 and Table 3-7, it is shown that the load and deflection values are obtained as follows:

- Define the curve of interest (NP = 5, 6, 7, 8, 9)
- Determine δ from $X \cdot LDP$ for the appropriate curve. For example, NP = 8, LDP = 2 inches (input data), and a nondimensional deflection equal to 1.5 would yield $\delta = 1.5 \times 2.0 = 3$ inches.
- Determine L from $P \cdot K \cdot LDP$ at the same nondimensional deflection (1.5) and curve type (NP = 8). In the above example, given a stiffness $K = 2 \times 10^5$ lb/in. From Figure 4-17, P = 0.5 and therefore:

$$L = 0.5 \times 2 \times 10^5 \times 2 = 2 \times 10^5 \text{ lb.}$$

If the deflection (δ) is known then one can compute X and, using the appropriate curve in Figure 4-17, obtain a value of P from which the load (L) can be determined as previously shown. Thus the user can readily identify load and deflection values for any particular internally coded nonlinear value.

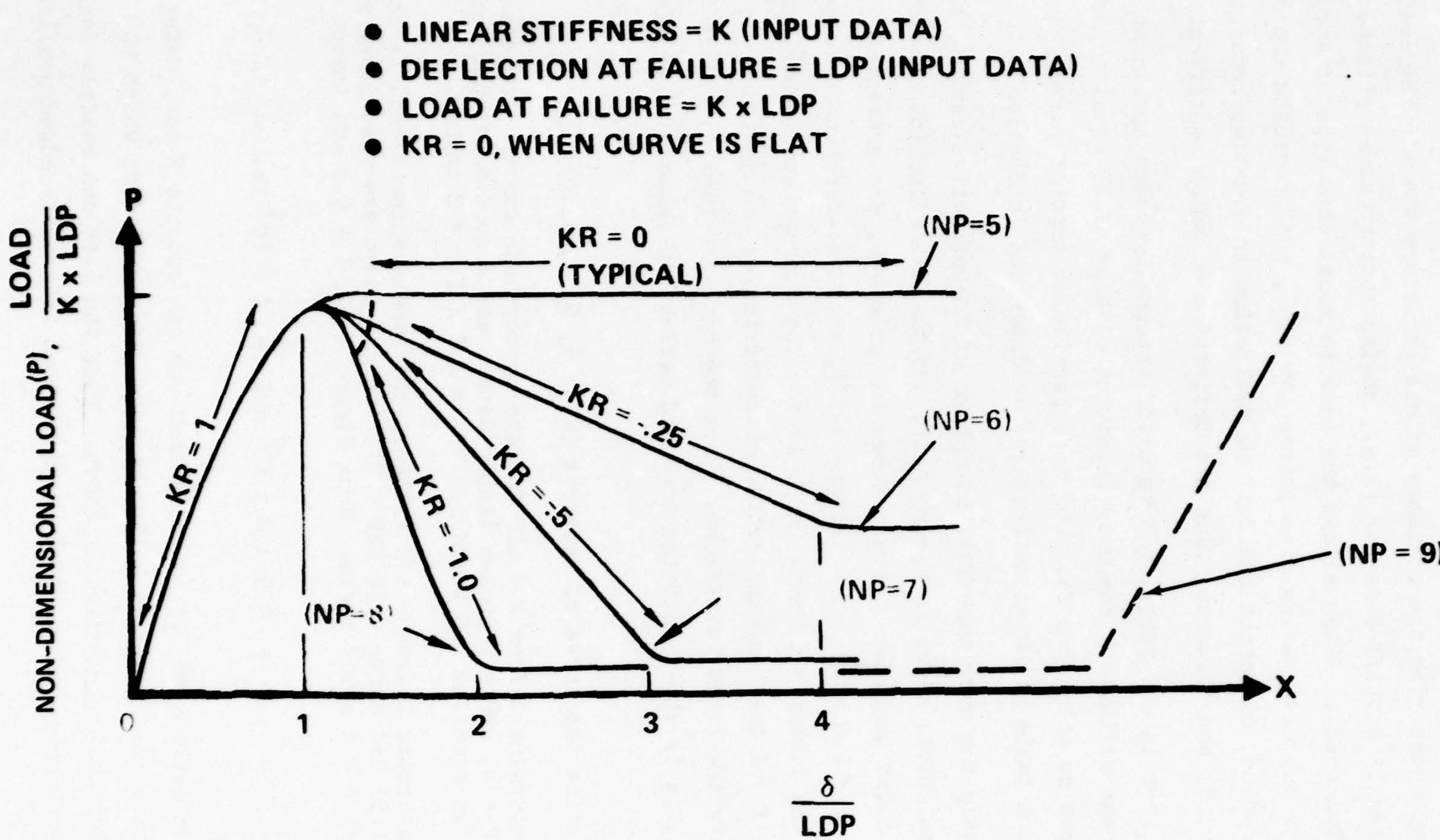


Figure 4-1' Relationship Between Load-Deflection and KR-Deflection Data

TABLE 4-5. KR DEFLECTION CURVES INTERNALLY CODED IN KRASH

AT POINT	NP = 5		NP = 6		NP = 7		NP = 8	
	KR	X	KR	X	KR	X	KR	X
0	1.0	0	1.0	0	1.0	0	1.0	0
a	1.0	LDP	1.0	LDP	1.0	LDP	1.0	LDP
b	0	> LDP	-0.25	4 * LDP	-0.5	3 * LDP	-1.0	2 * LDP
c	0	> LDP	0	>4 * LDP	0	>3 * LDP	0	>2 * LDP

LDP = deflection at failure load (input data)
NP = number of points defining an internally contained KR curve (input data)
X = deflection (contained within KRASH)

By using the information provided in this section which shows the relationship between forces, stiffnesses and KR factors, the user can program a wide range of nonlinear behavioral characteristics.

Thus far the discussion for internal members provides the user with the ingredients by which he can obtain linear properties and treat nonlinear behavior in KRASH. In order to use the nonlinear curves, the user is required to input a failure deflection value for each nonlinear curve. In reality, the failure deflection is obtained by predicting a failure load and determining the failure deflection using the known member linear stiffness. It is recommended that the prediction of failure loads be made using available analytical expressions for beams, columns, and frames. References 3 and 4 provide a literature survey discussing analytical methods. However, to facilitate the user's understanding of what is involved, the following two examples are given on how nonlinear data is obtained for: (1) estimating the axial failure deflection due to a column instability failure and (2) estimating the failure deflections and rotations based on beam stresses exceeding yield.

Example 1

Assume that a failure deflection value is needed in order to represent with program KRASH the buckling load failure of an engine mount. The available data are:

Modulus of Elasticity (E) = 30×10^6 lb/in^2

Area Moment of Inertia (I) = 0.19 in^4

Member length (ℓ) = 30 inches

Axial stiffness (K_{11}) = 7.2×10^5 lb/in.

Based on data provided in Reference 5 (Table XV, page 340, Case 1) KRASH contains expressions for computing the critical load (P') from the following two loading and support conditions:

Condition	Expression	
(1) Uniform straight beam under end load. Both ends hinged.	$P' = \dfrac{\pi^2 EI}{4\ell^2}$	(4-13a)
(2) Uniform straight beam under end load. Both ends fixed	$P' = \dfrac{4\pi^2 EI}{\ell^2}$	(4-13b)

Thus, for the member properties noted above and using expression (4-13a), the critical load P' is 15,627 lb. The axial deflection at the critical load is obtained from P'/K_{11} and equals 0.022 inches, which is the value of LDP that would be input into KRASH in the $\ell = 1$ (axial) direction.

Example 2

The following member properties are given:

Yield stress (σ) = 125,000 lb/in^2 (annealed steel)

Area moment of inertia (I) = 0.19

Distance from neutral axis to extreme fiber (-Z) = 0.425

Stiffness in bending (K_{33}) = 2670 lb/in

Length (ℓ) = 30 in.

It is desired to obtain an estimate of expected deflection at failure, based on the stresses exceeding yield. The procedure is as follows:

Establish the basic relationships

Moment (M) = Force x length = $\sigma I/Z$

Force = stiffness (K) x deflection (δ) thus;

$$\delta = \frac{\sigma I}{ZK\ell} \tag{4-14}$$

However, $K \neq K_{33}$ because the influence of rotation has to be considered. To do this, the coupled force (F) and moment (M) expressions for in-plane or out-of-plane bending have to be used. For the in-plane case the expression is:

$$\underset{\text{Force}}{\begin{Bmatrix} F \\ M \end{Bmatrix}} = \underset{\text{stiffness}}{\begin{bmatrix} K_{33} & K_{35} \\ K_{35} & K_{55} \end{bmatrix}} \underset{\text{deflection}}{\begin{Bmatrix} z \\ \theta \end{Bmatrix}} \tag{4-15}$$

where z = deflection, in.

θ = rotation, rad.

Reforming the equations:

$$z = \frac{K_{55}F - K_{35}M}{K_{33}\,K_{55} - K_{35}^{\;2}} \quad \text{and} \quad \theta = \frac{K_{33}M - K_{35}F}{K_{33}\,K_{55}\,K_{35}^{\;2}} \tag{4-16}$$

$$\Delta = K_{33}\,K_{55} - K_{35}^{\;2} \tag{4-17}$$

$$z = \left(\frac{K_{55}}{\Delta}\right) F - \left(\frac{K_{35}}{\Delta}\right) M \tag{4-18}$$

$$\theta = \left(\frac{K_{35}}{\Delta}\right) F + \left(\frac{K_{33}}{\Delta}\right) M \tag{4-19}$$

$$K_{33} = \frac{12EI}{\ell^3},\ K_{35} = \frac{6EI}{\ell^2},\ K_{55} = \frac{4EI}{\ell} \tag{4-20}$$

Therefore

$$\Delta = \frac{12EI}{\ell^3} \cdot \frac{4EI}{\ell} - \frac{6EI^2}{\ell^2} = \frac{12(EI)^2}{\ell^4} \qquad (4\text{-}21)$$

Assuming M = 0, one obtains from Equation 4-22

$$z = \left(\frac{4EI}{\ell}\right)\left(\frac{\ell^4}{12(EI)^2}\right)F = \left(\frac{\ell^3}{3EI}\right) F \qquad \text{and} \qquad \overline{K} = \frac{F}{z} = \frac{3EI}{\ell^3} \qquad (4\text{-}22)$$

Therefore, the equivalent stiffness is given by

$$\overline{K} = \frac{1}{4} K_{33} \qquad (4\text{-}23)$$

Using $K = \overline{K}$, the deflection (δ) is obtained from Equation (3-18)

$$\delta = \frac{(125{,}000)\ (0.19)}{0.425\ \left(\frac{2670}{4}\right)\ (30)} = 2.8 \text{ in.} \qquad (4\text{-}24)$$

The rotation due to a force F can also be determined from the first part of equation (4-19). Since this value does not include the effect that the moment has on the deflection, it should only be used as an initial trial value.

KRASH has provisions for calculating the initial trial nonlinear deflection values based on preliminary uncoupled loads following the expressions noted above. During the initial computer runs the member moment is available and the value can be used to determine if yield stress for the member has been reached. Assuming that the moment does not cause the member to yield the user can then determine what moment and force values will cause a yield failure, and using Equation (4-18), he can then refine his estimate of a failure deflection (δ) value to be input into KRASH. The user can also monitor stresses for individual elements to help determine the adequacy of the estimated deflection value at which nonlinearity occur.

Coupled effects are difficult to evaluate, and the procedures described herein are only approximate. For example, when an element is subjected to axial tension or compression in addition to transverse loads, the axial tension may tend to reduce the bending moment, while axial compression may

increase the bending moment. The solution to this problem cannot be obtained by simple superposition. The change in deflection produced by the axial load must be considered. The maximum stress in the extreme fiber of an internal element can be described by:

$$\sigma_{max} = \frac{P}{A} \pm \frac{M'}{I/Z} \tag{4-25}$$

where

P = axial load

A = cross sectional area

I/Z = section modulus

M' = maximum bending moment due to the combined effect of the axial and transverse loads

M' can be obtained with sufficient accuracy by the following approximate formula from Reference 4.

$$M' = \frac{M}{1 \pm \alpha \frac{P\ell^2}{EI}} \tag{4-26}$$

where $\alpha = 1/3$ for a cantilevered beam with an end load. Additional formulas for various beam configurations under combined axial and transverse loading are provided in Reference 5.

These and other approximate techniques can be used effectively as a means of verifying analytical results as well as for establishing initial input parameters.

Program KRASH calculates uncoupled preliminary loads and deflections to use as a first estimate of data for determining nonlinear deflections. Experience has shown that in a coupled loading condition the user should monitor the element stresses for the particular loading encountered, and establish deflections for KR curves based on these results.

While reliance on stress has limitations (Section 4.8), the use of stress as a monitoring tool to assess if yield has been reached offers some advantage to the user. The user should be looking for consistency between load, deflection, stress, and/or failure to ascertain the validity of the model.

4.6 MASSLESS NODES

KRASH allows the user to define node points which are massless. These points are rigidly connected to mass points. With this capability the user can attach internal beams and external springs at points other than the cg of a lumped mass. This feature can be helpful in modeling a seat and an engine on its mount.

While KRASH has the capability to model 80 masses, mass locations cannot be arbitrarily assigned, particularly in regions wherein light weight structure is located. Experience in modeling light fixed-wing airplane structure has indicated that reasonable care must be taken in selecting mass locations such that element response frequencies are compatible with the integration interval. The higher the element frequency, the smaller the integration interval (and higher the cost to perform an analysis) that is required to maintain a stable system. Two areas that are particularly vulnerable in this regard are:

1. Rigorous modeling of a finite mass (engine) which has several attach points.

2. Rigorous modeling of a seat system.

Both systems involve a network of extremely light members (struts, seat legs) if all node points are to be presented. Figure 4-18 shows a typical tubular engine mount arrangement. The engine is a relatively large mass, attached to its mounting bed at 1 and 2 (one side shown). The tubular supporting structure, in turn, attaches to the firewall at points A and B (one side shown). Without the use of massless nodes the user has to idealize the engine and its mounts as a lumped mass with the weight at the cg and the upper and lower mounts each as internal beam members (dashed lines in Figure 4-18) which represent stiffness properties in six directions for more than one tubular member. However, with the use of massless nodes the user

can model directly each mount at its appropriate attach point. For example, the engine mount arrangement can now be modeled with flexible members having the area properties of individual tubes connecting point A to 2 and B to 1 and 2 (Figure 4-18) for each side. Program KRASH contains rigid body equations which relate to these nodes to the mass (at cg of engine in this case).

In addition, one can add nodes at any point on the engine. For example, node point 3 (Figure 4-18) could represent an accelerometer location whose response is to be monitored during a test or is available from previous test data. Similarly, at the firewall to which points A and B attach, the user can specify nodes which are rigidly connected to a mass representation of the firewall at a more convenient location.

Figure 4-19 shows a typical pilot or copilot powered adjustable seat configuration. The modeling arrangement without benefit of massless nodes is shown in Figure 4-20. Since the seat pan and floor structure, in the region of the seat legs, are relatively light weight areas, it is difficult to model with much detail. Ideally 4 masses should represent the seat pan. However, this causes a potential integration related instability problem. The user,

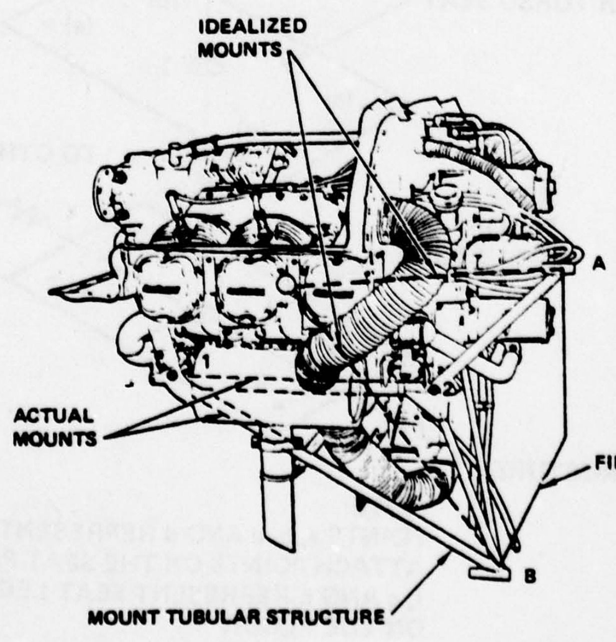


Figure 4-18. Typical Tubular Engine Mount Arrangement

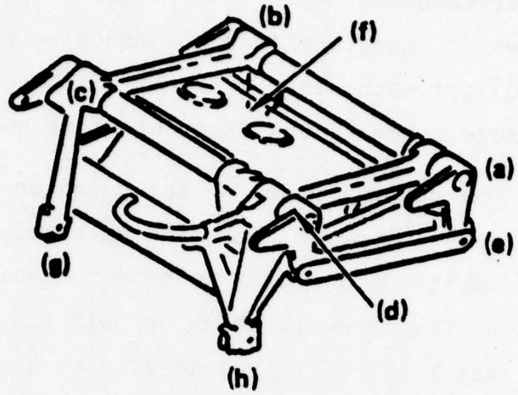


Figure 4-19. Typical Pilot or Copilot Power Adjustable Seat Configuration

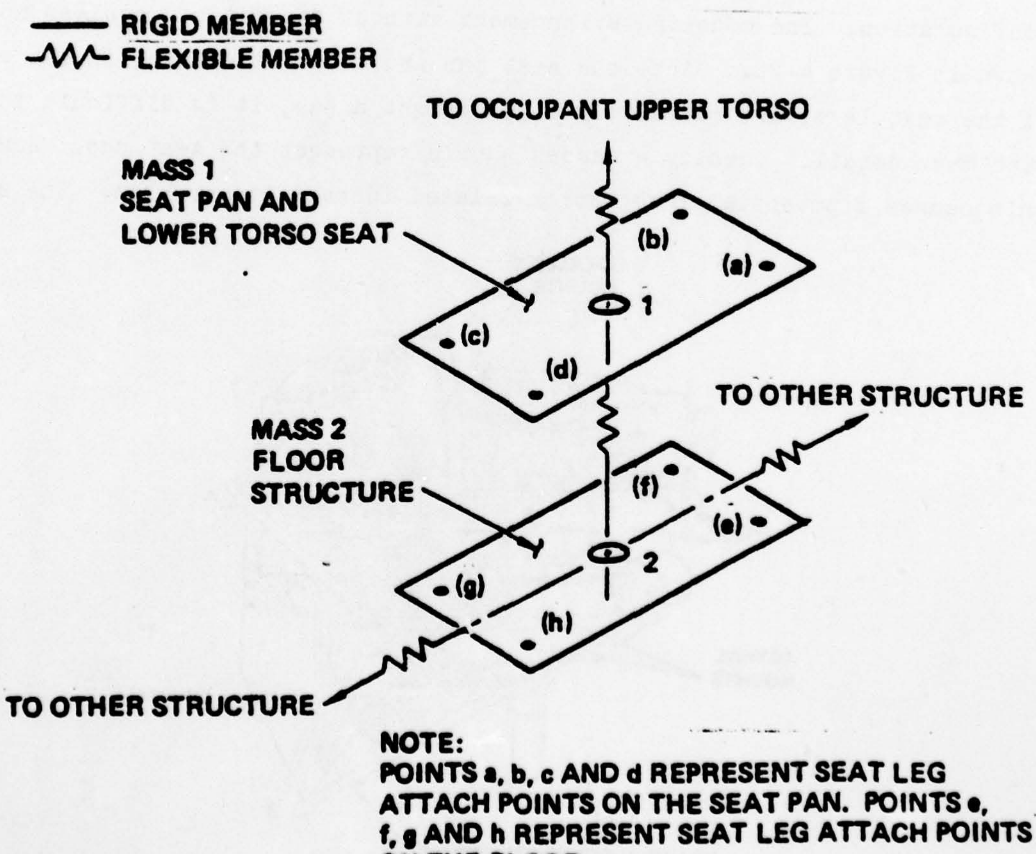


Figure 4-20. Model Arrangement in KRASH Without Massless Nodes

therefore, has to compromise and represent the seat legs with one member. This requires representing the response characteristics of several floor members with one beam as well as idealizing the seat legs as another individual member.

With the application of massless nodes, the user can represent the occupant-seat-floor arrangement as shown in Figure 4-21. Massless nodes are established at each seat leg-floor attachment point and at each corner of the seat pan. Each of the seat legs is modeled as a column. Points 1 through 5 are mass locations and points (a) through (h) are massless node points. Mass point 1 represents the seat pan and occupant's lower torso.

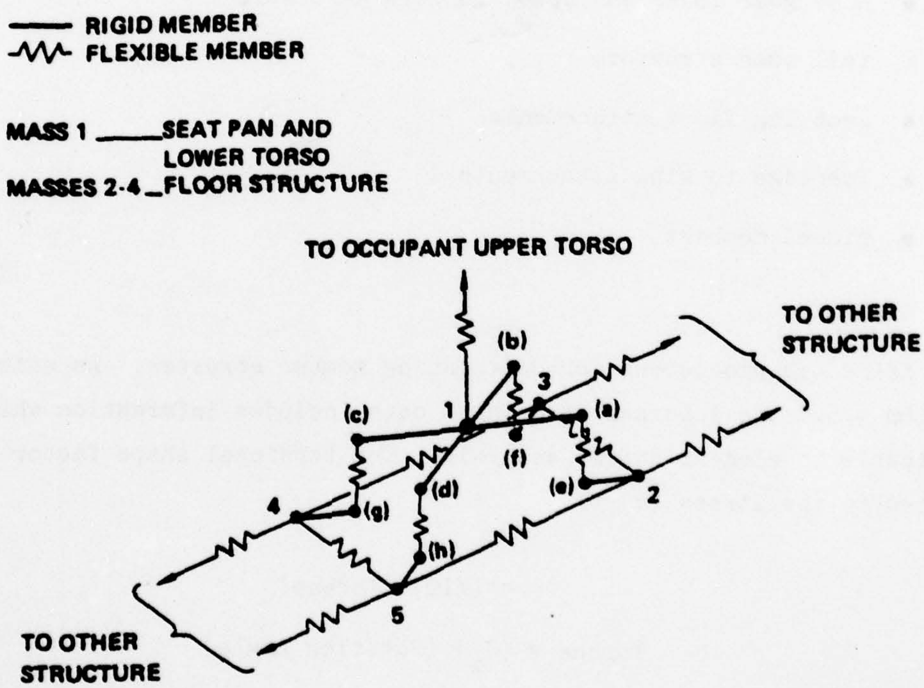


Figure 4-21. Model Arrangement in KRASH With Massless Nodes

4.7 FORCE AND DEFLECTION RUPTURE

Program KRASH provides for the loss of structure in the event a maximum force or deflection is exceeded in any of the 6 directions associated with each internal beam element. Unless a rupture force or deflection is specified the program allows for deflections and rotations of 100 inches and radians, respectively, and 10^{10} pounds or in. lbs. for force and moment, respectively. Wherein structure fails to the point that no load can be carried by the particular member, it can be designated a rupture element and the maximum allowable force or deflection and associated direction have to be defined. This feature is particularly useful for representing such elements as:

- landing gear bulkhead attach points
- nose gear lower and upper support structure
- tail cone structure
- seat leg floor attachments
- fuselage to wing attachments
- pinned members

4.8 STRESSES

KRASH has provisions for calculating member stresses. As noted in Section 4.5.1 the internal beam input data includes information which is applicable to element stress analysis. The torsional shape factor XIQ is related to the stress (σ) by

$$\sigma = (XIQ)\ (Torque)$$

$$Torque = (J_x)\ (Rotation\ Angle)$$

Table 4-6 (obtained from Reference 5, Table IX) shows typical formulas by which J_x and XIQ can be obtained. J_x is the torsional stiffness factor and equals the K term in column 2 of Table 4-6. XIQ is equal to the term which relates maximum stress (σ) to torque in column 3 of Table 4-6. The terms Z1 and Z2 are the distance from the y neutral axis and z neutral axis to their respective extreme fibers.

TABLE 4-6. FORMULAS FOR TORSIONAL DEFORMATION AND STRESS (REFERENCE 5, TABLE IX)

General formulas: $\theta = \frac{TL}{KG}$, $s = \frac{T}{Q}$, where θ = angle of twist (rad); T = twisting moment (in.-lb); L = length (in.); s = unit shear stress (lb. per sq. in.); G = modulus of rigidity (lb. per sq. in.); K (in.^{4}) and Q (in.^{3}) are functions of the cross section.

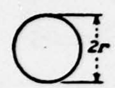
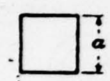
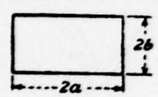
Form and dimensions of cross sections, other quantities involved, and case number	Formula for K in $\theta = \frac{TL}{KG}$	Formula for shear stress
1. Solid circular section 	$K = \frac{1}{2}\pi r^4$	Max $s = \frac{2T}{\pi r^3}$ at boundary XIQ $= \frac{2}{\pi r^3}$
2. Solid elliptical section 	$K = \frac{\pi a^3 b^3}{a^2 + b^2}$	Max $s = \frac{2T}{\pi a b^2}$ at ends of minor axis
3. Solid square section 	$K = 0.1406a^4$	Max $s = \frac{T}{0.208a^3}$ at mid-point of each side
4. Solid rectangular section 	$K = ab^3\left[\frac{16}{3} - 3.36\frac{b}{a}\left(1 - \frac{b^4}{12a^4}\right)\right]$	Max $s = \frac{T(3a + 1.8b)}{8a^2b^2}$ at mid-point of each longer side

TABLE 4-6. FORMULAS FOR TORSIONAL DEFORMATION AND STRESS (REFERENCE 5, TABLE IX) (Continued)

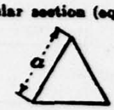
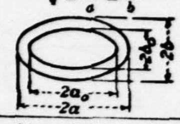
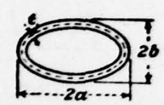
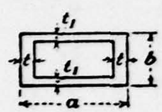
5. Solid triangular section (equilateral) 	$K = \frac{a^4\sqrt{3}}{80}$	Max $s = \frac{20T}{a^3}$ at mid-point of each side
6. Hollow concentric circular section 	$K = \frac{1}{2}\pi(r_1^4 - r_0^4)$	Max $s = \frac{2Tr_1}{\pi(r_1^4 - r_0^4)}$ at outer boundary
7. Hollow elliptical section, outer and inner boundaries similar ellipses $q = \frac{a_0}{a} = \frac{b_0}{b}$ 	$K = \frac{\pi a^3 b^3}{a^2 + b^2}(1 - q^4)$	Max $s = \frac{2T}{\pi a b^2(1 - q^4)}$ at ends of minor axis on outer surface
8. Hollow, thin-walled elliptical section of uniform thickness. U = length of median boundary, shown dotted $U = \pi(a + b - t)\left[1 + 0.27\frac{(a-b)^2}{(a+b)^2}\right]$, approx. 	$K = \frac{4\pi^2 t[(a - \frac{1}{2}t)^2(b - \frac{1}{2}t)^2]}{U}$	Average $s = \frac{T}{2\pi t(a - \frac{1}{2}t)(b - \frac{1}{2}t)}$ (stress nearly uniform if t is small)
9. Any thin tube of uniform thickness. U = length of median boundary, A = mean of areas enclosed by outer and inner boundaries, or (approx.) area within median boundary 	$K = \frac{4A^2 t}{U}$	Average $s = \frac{T}{2tA}$ (stress nearly uniform if t is small)

TABLE 4-6. FORMULAS FOR TORSIONAL DEFORMATION AND STRESS (REFERENCE 5, TABLE IX) (Continued)

Form and dimensions of cross sections, other quantities involved, and case number	Formula for K in $\theta = \frac{TL}{KG}$	Formula for shear stress
10. Any thin tube. U and A as for Case 9; t = thickness at any point 	$K = \frac{4A^2}{\int \frac{dU}{t}}$	Average s on any thickness $AB = \frac{T}{2tA}$ (Max s where t is a minimum)
11. Hollow rectangle 	$K = \frac{2tt_1(a-t)^2(b-t_1)^2}{at+bt_1-t^2-t_1^2}$	Average $s = \frac{T}{2t(a-t)(b-t_1)}$ near mid-length of short sides Average $s = \frac{T}{2t_1(a-t)(b-t_1)}$ near mid-length of long sides (There will be higher stresses at inner corners unless fillets of fairly large radius are provided)
12. Thin circular open tube of uniform thickness. r = mean radius 	$K = \frac{2}{3}\pi r t^3$	Max $s = \frac{T(6\pi r + 1.8t)}{4\pi^2 r^2 t^2}$, along both edges remote from ends (this assumes t small compared with mean radius; otherwise use formulas given for Cases 14 to 20)
13. Any thin open tube of uniform thickness. U = length of median line, shown dotted 	$K = \frac{1}{3}Ut^3$	Max $s = \frac{T(3U + 1.8t)}{U^2t^2}$, along both edges remote from ends (this assumes t small compared with least radius of curvature of median line; otherwise use formulas given for Cases 14 to 20)

The user can request stress calculations. However, if stress calculations are to be made, the input data must include appropriate information for XIQ, Z1 and Z2. Most likely, only selected member stresses will be of concern because (a) the member lends itself to stress computations, (b) the stress parameter data are available, and (c) it is important to monitor the element response to yield. In this situation, the user can input stress parameter data as accurately as it is known for the elements of concern and request a summary print and plot of these data. For the other elements zero values will produce meaningless stress ratios but will not disrupt the analysis. Since these data can be suppressed, the user will obtain only the data that is desired.

Stress equations and criteria are described in the KRASH User's Manual, Reference 1. The user is cautioned to be aware that the stress data should be interpreted only as an indication of the occurrence of plastic deformation, and should not be used as an absolute measure of stress. In selecting a member to monitor for stresses, the user should attempt to apply the stress ratio to those members that have been represented as close to the actual structure as possible. The more gross the representation of a structural region that is being approximated in KRASH, the less accurate the stress values and the interpretation of the data. Failure of an element due to instability (buckling) can also be monitored with the stress calculations. Tubular mounts under axial loading are susceptible to this type of failure.

The user should recognize that once an element has yielded, the failure theories are invalid and, consequently, the most meaningful use of the stress data is to identify which elements may fail and when such failures may occur. These data are to be reviewed with an eye toward assessing the validity of the results. Stress terms do not include the effect of stress concentrations, unique geometrical shapes, and detail attachment practices at joints. In addition, the user will rarely have an opportunity to validate stress results. In practice, it is very difficult to interpret measured stress data (from strain gages) wherein large deformations occur. Most of the strain gage data is valid for linear responses and is an indication of local behavior.

4.9 VOLUME

KRASH has routines which define the occurrence of a volume being penetrated and the approximate change in volume. The volume penetration calculation is limited to noting when such an occurrence takes place. The user can obtain the velocities and masses involved and perform additional analysis if he so chooses. KRASH, at present, does not attempt to analyze this situation any further. This feature can only be used to detect when a heavy mass located near occupiable volume, in failing, could cause a potential hazard to people in an occupiable region. The second volume routine provides a first order approximation of the volume change in one or more selected regions. Volume Penetration and Change computations are described in the KRASH User's Manual, Reference 1.

4.10 DYNAMIC RESPONSE INDEX (DRI)

The DRI represents one measure of injury severity. It is only valid for evaluating the potential of a spinal vertical compression injury. It is easy to model in KRASH and as a matter of course should be included in every model wherein occupants are included. It only adds one mass and one member to the structural model which is an insignificant cost. Where high sink rates are involved, it will provide a useful evaluation of the effect of impact severity for one type of injury (vertebrae compression). The user needs to specify appropriate mass location of the DRI. The program computes the appropriate damping coefficients and the stiffness for the DRI beam. The proper distribution of mass between occupant and seat is noted in Section 1.3.12 of Volume I. Normally one distributes the occupant's mass as 44 percent (upper torso) for the DRI mass, 44 percent (lower torso) for the seat and 12 percent (lower limbs) for the floor. For predominantly longitudinal impacts, the DRI will be of little value. If a harness is employed, it is possible for the user to approximate its restraining effects with a member from the occupant to structure. KRASH has the capability to define tension-only members which can be used to represent harnesses and/or seat belts. However, at present, occupant-restraint systems should be used for evaluating occupant motion. Reference 8 (Figure 1-12) provides a set of data from which the probability of spinal injury is related to DRI values.

4.11 STRUCTURAL REPRESENTATIONS

The development of a mathematical model which is capable of predicting the dynamic response of structure and occupants for light fixed-wing airplanes during severe, yet survivable, accidents requires that consideration be given to those conditions that influence the manner in which the structure containing habitable space deforms and the forces that are imposed on the occupant from the response of the airplane structure and/or the occupant's motion relative to hardware that he may impact. Examples of airplane configuration design characteristics that potentially influence the load pulse imparted to the seat during a crash are:

- Location of the wing relative to the cabin and occupant position.
- Location of engine, or engines, with respect to the cabin; wing mounted (high or low), forward or aft.
- Seat design and location.
- Type and location of landing gear; fixed or retractable.

The loads imposed on the airframe and the occupants are a function of airplane usage, structural design, and location and attachment of major masses. In Reference 2 a comprehensive discussion of airplane configurations, usage, accident conditions and the consequence to the occupants of accidents is presented. This section of the KRASH manual discusses the types of structures and the manner in which modeling data is obtained.

Table 4-7 identifies the general structural design characteristics of the major airframe regions such as the wing, fuselage, engine attachments, landing gear, and empennage associated with different categories of airplanes. (The categories shown in Table 4-7 are defined in Reference 1). Typical structure in each of the regions is briefly discussed in the following subsections. Since there are many variations in detail design from manufacturer to manufacturer, the following discussion is limited to sample examples and is not all inclusive. However, it is felt that the approaches noted are applicable to a broad spectrum of structural designs.

TABLE 4-7. STRUCTURAL DESIGN CHARACTERISTICS OF CURRENT GENERAL AVIATION AIRPLANES

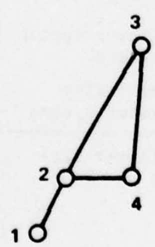
Structure	Category 1 Single-Engine, Low or High-Wing, Weight < 2500 lb.	Category 2 Single-Engine, Low or High-Wing, Weight 2500-4000 lb.	Category 3, Single-Engine, Low-Wing, (a) Agricultural Use Only, Weight 2500-4000 lb.	Category 4 Twin-Engine, Low or High-Wing, Weight 4000-10900 lb.
Wing	o Braced Wing 1,2 or 3 spar, mostly metal, some wood spars o Cantilever 1,2 or 3 spar, mostly metal, some wood spars	o Cantilever 1,2 or 3 spar mostly metal, some wood spars	o Braced 1 or 2 spar metal construction	o Cantilever 1,2 or 3 spar, mostly metal, some wood spars o One braced, all metal
Fuselage	o All-metal semi-monocoque o Rectangular section welded steel tube o Keel formed by floor and lower skin (cabin), semi-monocoque (rear)	o All-metal semi-monocoque o Weld steel tube o Welded steel tube (cabin), semi-monocoque (rear)	o Rectangular section welded steel tube o Welded steel tube (cabin), semi-monocoque (rear) o Long nose section o Isolated occupant region o Strong turnover structure	o All-metal semi-monocoque
Engine Attachment	o Tubular	o Tubular o Keel	o Tubular	o Tubular o Keel
Landing Gear	o Tail wheel o Tricycle o Cantilever spring main gears o Nonretractable	o Tail wheel retractable o Tricycle retractable and nonretractable o Cantilever spring main gears o Hydraulically activated system	o Tail wheel type o Nonretractable o Cantilever spring main gears	o Mostly tricycle retractable o Some nonretractable with cantilever spring main gears o Hydraulic or electromechanical actuated system
Tail Unit	o Cantilever all-metal o Welded steel tube and channel with fabric covering	o Cantilever all-metal	o Welded steel tube o Cantilever all-metal	o Cantilever all metal

(a) With the exception of one biplane

4.11.1 Landing Gears

Cantilever spring gears are very commonplace for the lighter (≤ 4000 lbs.) airplanes. A typical main landing gear arrangement is shown in Figure 4-22. The landing gear attaches to the main tire at the axle. The tire is modeled as a mass and an external spring in KRASH. The load-deflection characteristics of the tire are obtained from standard tire data. The main gear itself is modeled as an internal beam. Based on a typical cross section, the beam properties are computed. Since in the linear region a constant set of area and area moment of inertia terms are used, the user should select a section which 'on the average' will represent the behavior of the element. Experience has shown that the type of spring shown in the figure remains linear for as much as 16 inches of stroke. In fact, failures that occur usually occur at the attachment of the gear to the fuselage structure. Load-deflection data from normally planned tests to show design load capability can be used to supplement analysis for this particular element. Since the bolt attachment to the fuselage could prove to be the weakest link in this system, the user is advised to include another internal member between the landing gear and fuselage with characteristics exhibiting abrupt failure when the load capability is exceeded in either of the three directions (x y, z).

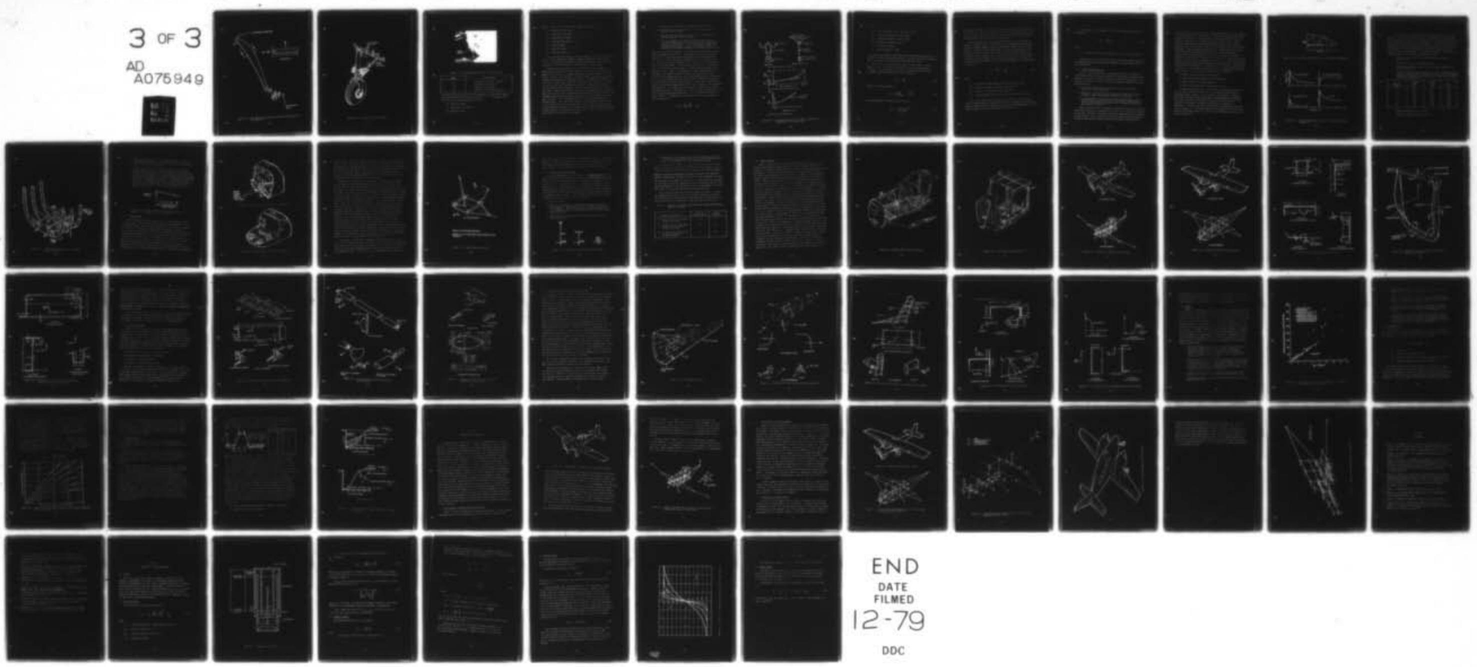
A nose landing gear is shown in Figure 4-23. The gear attaches to the firewall with two supports, upper and lower, as shown in Figure 4-24. The user can model this structure as shown below:



MASS	REPRESENTATION
1	tire
2	nose gear lower structure
3	nose gear upper structure
4	firewall structure

AD-A075 949 LOCKHEED-CALIFORNIA CO BURBANK F/G 1/3
GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS USER'S MAN--ETC(U)
SEP 79 M A GAMON , G WITTLIN , W L LABARGE DOT-FA75WA-3707
UNCLASSIFIED LR-28307-VOL-2 FAA/RD-77/189-V2-REV NL

3 OF 3
AD
A075949



END
DATE
FILMED
12-79
DDC

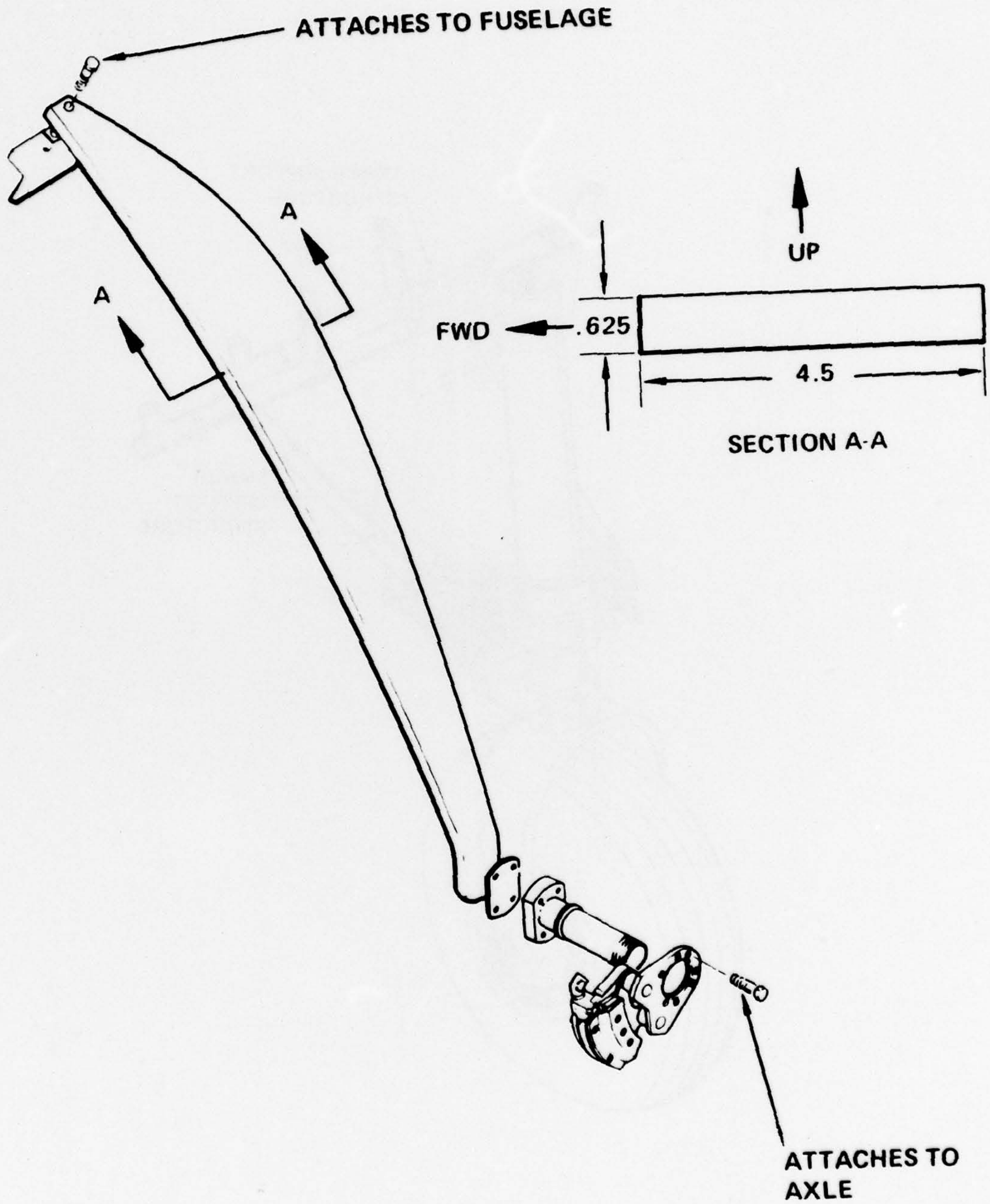


Figure 4-22. Main Landing Gear Cantilever Spring and Representative Cross-Section

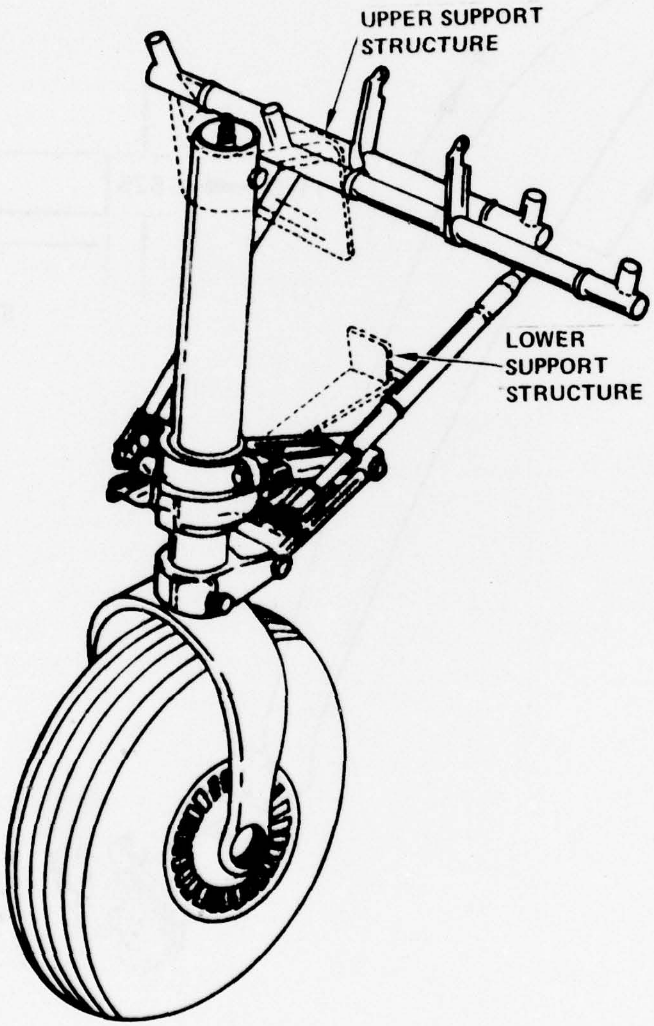


Figure 4-23. Nose Gear and Tire Structure

Figure 4-24. *Nose Gear Upper and Lower Support Structure*

MEMBER	REPRESENTATION
1-2	nose gear from tire to trunnion
2-3	nose gear upper support
2-4	nose gear lower support
3-4	firewall region between supports

In analyzing the structure the user can determine the potentially weakest area in the system for different directional forces. For example, with a fore-aft load the potential weakest areas are:

(a) upper bolt tension

(b) lower mount bolt bearing

(c) upper bolt shear

and with a vertical load the potential weakest areas are:

(a) lower mount rivet shear

(b) upper mount rivet shear

(c) upper mount bolt shear

(d) lower mount bolt shear

(e) ring bolt shear

(f) upper bolt shear

(g) upper bolt bearing

With these data, the user can then model members 2-3 and 2-4 with rupture failure loads or deflections (based on element stiffnesses). When these loads or deflections are reached the support structure will fail allowing the nose gear to rotate and the rest of the structure to absorb energy.

Nose gear modeling generally is not important from the standpoint of energy that is absorbed at initial impact or to failure. As a rule, the nose gear fails with little or no significant amount of energy taken out of the system. However, it is important to model the manner in which the member fails inasmuch as it effects the subsequent events. For example, in a nose down impact with a steep impact angle (θ) the gear will most likely fail such that it would move aft and fold under the cabin floor. However, in a flared landing (negative flight path angle (γ) and a positive θ) the gear can fail such that it would rotate forward. The user must recognize that to model the events following the failure accurately an equivalent nonlinear spring must be represented between the ground and the region of structure wherein the nose gear can lodge. As a first approximation of load the user can use tire characteristics. The location and length of the equivalent nonlinear spring can be obtained by laying out the geometry of the vehicle and superimposing a failed nose gear position. If necessary, the load can be distributed among adjacent masses. To determine the position (fore or aft) of the nose gear the user can do one or more of the following:

(a) Analyze the load conditions to determine type of failure.

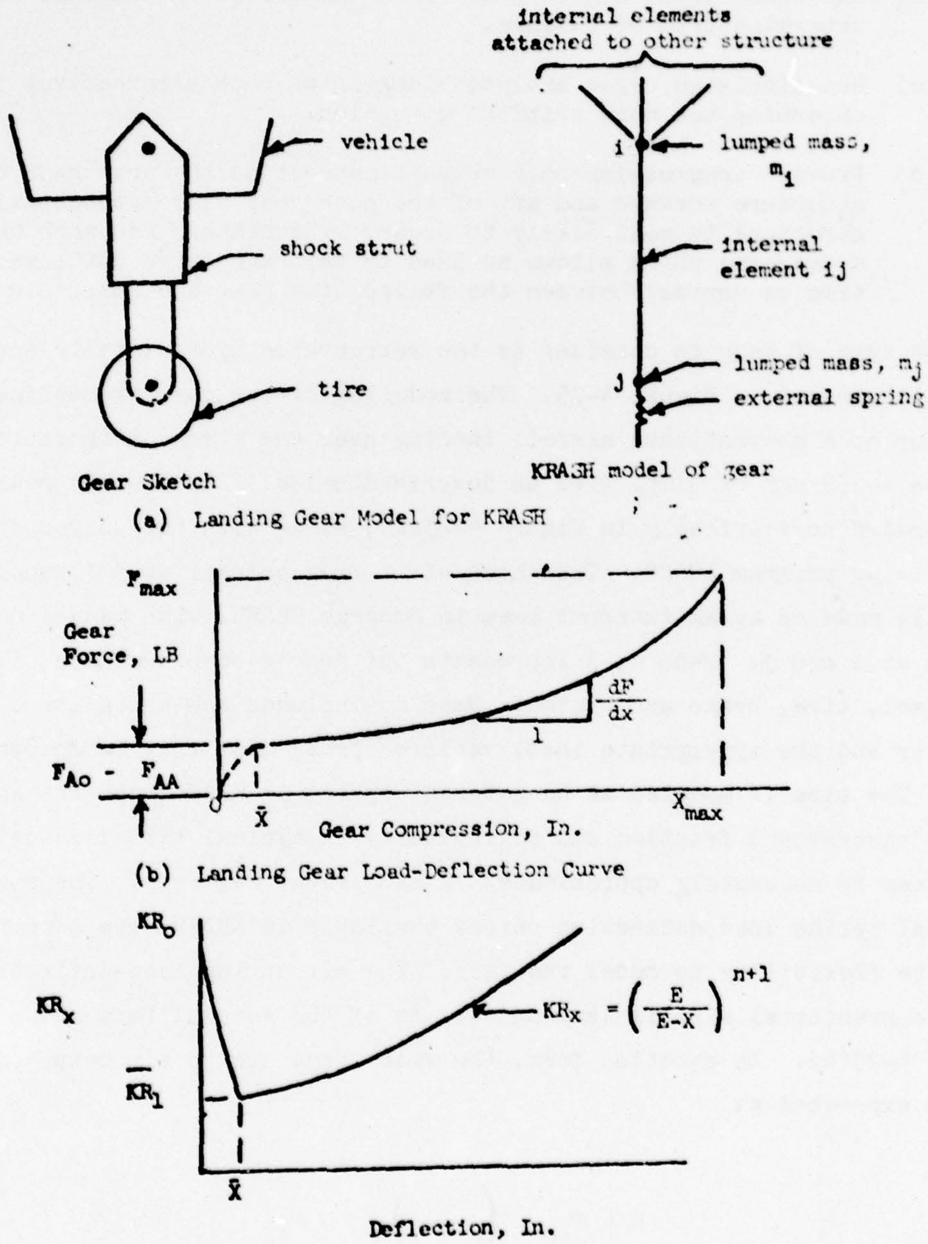
(b) Run KRASH until a nose gear fails and review the results to determine type of failure.

(c) Run simulated crash analysis looking at both alternatives to determine the more critical situation.

(d) Provide compression only members connecting the nose gear to structure forward and aft of the nose gear where contact with structure is most likely to occur. The members can each have a deadband which allows no load to be transmitted until such time as contact between the failed nose gear and structure occurs.

Another type of gear to consider is the retractable hydraulically actuated type illustrated in Figure 4-25. The modeling of the complex nonlinear behavior of a conventional air/oil landing gear and tire configuration (Figure 4-25) can be simplified as described below. The landing gear is illustrated schematically in Figure 4-25(a), along with the corresponding model using program KRASH. The shock strut from point i to j (trunnion to axle) is modeled as an internal beam in program KRASH, with masses concentrated at i and j. Mass m, j represents the gear's unsprung mass, i.e., the wheel, tire, brake and piston. Mass m_i includes the shock strut cylinder and the appropriate local vehicle sprung mass that is concentrated at i. The tire is modeled as an external spring in KRASH, and the appropriate tire/ground friction can be included. A typical tire load-deflection curve can be accurately approximated by two linear segments. The standardized external spring load-deflection curves available in KRASH have more than adequate flexibility to model the tire. The air spring load-deflection curve for a conventional air/oil landing gear is of the general form shown in Figure 4-25(b). In equation form, the gear force due to air compression can be expressed as

$$F = F_{AO} \left(\frac{E}{E - x}\right)^n - F_{AA} \qquad (4\text{-}27)$$



(a) Landing Gear Model for KRASH

(b) Landing Gear Load-Deflection Curve

(c) KR Curve for Landing Gear

Figure 4-25. Retractable Hydraulically Actuated Landing Gear Representation for Program KRASH

where

F = Gear force due to air compression, pounds

F_{AO} = Fully extended gear preload, pounds

E = Effective pneumatic stroke, inches

F_{AA} = Ambient air preload, pounds

n = Polytropic exponent

x = Gear compression, inches

E, F_{AO} and F_{AA} are readily calculated from the geometric properties of the gear and the piston extended air pressure. Alternatively, these parameters can be calculated from the furnished load-deflection curve.

The KR curve associated with this type of landing gear is shown in Figure 4-25(c). The value of the transition point $\bar{X}$ is chosen small ($0.01X_{max.}$). By assuming $\bar{X} \ll E$ and $F_{AA} \ll F_{AO}$ (normally the case), the following simplified expression for KR_o is obtained:

$$KR_o = \frac{2E}{n\bar{X}} - 1 \qquad (4\text{-}28)$$

The initial linear stiffness is

$$K_X = \left(\frac{dF}{dX}\right)_{x=0} = \frac{nF_{AO}}{E} \qquad (4\text{-}29)$$

and the expression for KR as a function of X is

$$KR_X = \left(\frac{E}{E - X}\right)^{n+1} \qquad (4\text{-}30)$$

K_X represents element 1,1 of the 6 x 6 stiffness matrix for the landing gear and the product K_X times KR_X represents the axial load-deflection rate. The five directions, other than the axial, would be treated in the same manner as internal elements are now treated in program *KRASH*.

Typical aircraft oleo type landing gears utilize oil flow through an orifice to achieve damping. This process is best represented as hydraulic (velocity-squared) damping, whereas program KRASH utilizes viscous (linear) damping. In addition, real landing gears have strut friction which is not explicitly modeled in KRASH. To account for these nonlinear effects, an equivalent viscous damping constant can be determined based on equal energy dissipation over one-quarter cycle of sinusoidal response. Following the procedure described in Reference 6 the resulting equation for a linear damping coefficient is:

$$C_L = \frac{8C_H V_e}{3} + \frac{4F_F}{\pi V_e} \qquad (4\text{-}31)$$

where

C_L = Equivalent linear damping coefficient, pound - sec/in

C_H = Hydraulic damping coefficient, pound sec^2/in^2

F_F = Coulomb or constant friction force, pound

V_e = Equivalent peak velocity of sinusoidal oscillation, in/sec

For a crash impact, the oscillation of interest is the first quarter cycle of response when the sprung mass starts at its peak impact velocity and ends up at zero velocity. Therefore, as a first order approximation V_e can be taken as equal to the vehicle vertical impact velocity.

From Reference 1. the damping input constant required in KRASH can be expressed as:

$$C_{ij} = \frac{\omega_k}{2K_x} C_L \qquad (4-32)$$

where

ω_k = beam natural frequency (equations 1-55(a), 1-55(b), Volume I)

The expressions for K_X, KR_o, KR_x and $\bar{C}_{ij}$ provide the required input data for representing an approximate axial stiffness and damping for an air/oil oleo landing gear.

4.11.2 Lower Fuselage Structure

During a crash condition the crushing characteristics of forward and lower fuselage structure generally account for the majority of energy that is absorbed in reducing the kinetic energy and slowing down the vehicle. This structure is difficult to model as individual elements in KRASH for several reasons including:

- Individual element failure modes are difficult to accurately predict on a consistent basis.
- Modeling of light weight stiff structure could result in program instability when using numerical integration techniques.
- The large number of mass nodes and interconnecting members result in an extremely large model with an appropriately large amount of detailed input data, and associated costs to perform the analysis and evaluate the results.

Ideally, one would like to represent crushable structure with an external spring which represents the load-deflection behavior of a substantial segment of structure. Section 4.4 provides a discussion regarding the use of external springs in KRASH. Usually the prediction of the energy absorbing capability of general substructures requires post-failure analyses characterized by

deflections which are several orders of magnitude larger than the usual deflections associated with the design loads. Significant advancements have been achieved in the area of large deformation nonlinear structural analysis by computer oriented finite difference and finite element methods. Wherein simplified approaches are sufficiently accurate, they are obviously more desirable from a cost and ease of application standpoint than the more complex approaches. One such simplified approach which appears adequate for determining nonlinear load-deflection characteristics of typical crushable integrated sheet metal/stringer type structures is described in detail in Reference 4 and is briefly discussed in this subsection. Since the method has been verified with static and dynamic test data, it is of particular interest in application to similar light fixed-wing airplane structure. The simplified method described in Reference 4 is applicable to the structural segment shown in Figure 4-6. The specimen that was fabricated to represent the structure is shown in Figure 4-5. The step by step analytical procedure is:

- Predict failure loads for stiffened panels
- Perform post-failure analyses of stiffened panels
- Perform beam and bottom skin analyses
- Obtain total substructure load-deflection curve

The procedure takes into account monolithic, wrinkling, and interrivet failure modes as noted in Figure 4-26. The procedure is applicable to slenderness ratios $(L/\varphi) \geq 20$. The procedure is applicable to a variety of panel types including T-type, formed angle, and extruded angle stiffeners, hat-formed or extruded Y stiffeners and formed multicorner sections. An outline of the procedure, assumptions and results is presented in Reference 4. A typical test result and comparison of analysis and test are shown in Figure 4-7. Individual subelement load-deflection curves are superimposed in a piecewise manner to obtain a total load-deflection curve, as is shown in Figure 4-27.

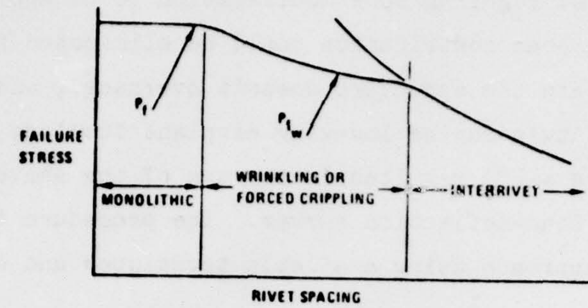


Figure 4-26. Various Failure Modes of Short Riveted Panels (Reference 7)

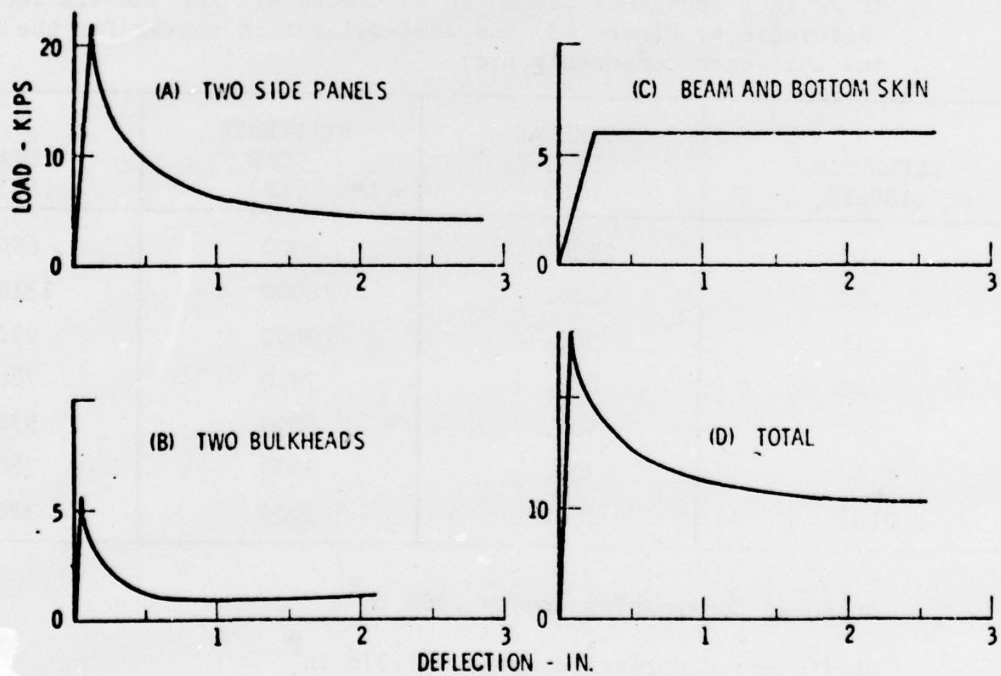


Figure 4-27. Predicted Subelement and Total Load-Deflection Curves (Reference 4)

The procedure described herein and in Reference 4 indicates one general approach. It requires some modification to be applicable to other structure (i.e., main beam contribution could be eliminated for different support conditions, wherein the structure doesn't overhang), and other loading conditions. Analysis of twin-engine low-wing airplane fuselage structure for crashworthiness (Figure 4-28) resulted in the use of the above noted procedure for developing load-deflection curves. The procedure followed is outlined as one suggested approach using available techniques and data:

1. Select a region of the lower fuselage to be represented by an external spring.

2. Determine the depth of the region selected.

3. Determine the projected area in the ground plane encompassing the structure dimensions.

4. Compare the structure's projected area with that of either the 6 inch or 12 inch specimens tested in Reference 4. For the six inch specimen (Reference 4, Figure 43) the load-deflection curves for the bulkhead and stiffener components are:

DEFLECTION (INCHES)	BULKHEAD LOAD (LB)	STIFFENER LOAD (LB)	TOTAL (LB)
.05	2500.	4000	6500
.10	1100.	12000	13100
.15	900.	9000	9900
.20	800.	7000	7800
.40	500.	5000	5500
1.0	300.	3500	3800
2.0	200.	3000	3200

Bulkhead Compression area = .956 in^2

Stiffeners Compression areas = 3.376 in^2

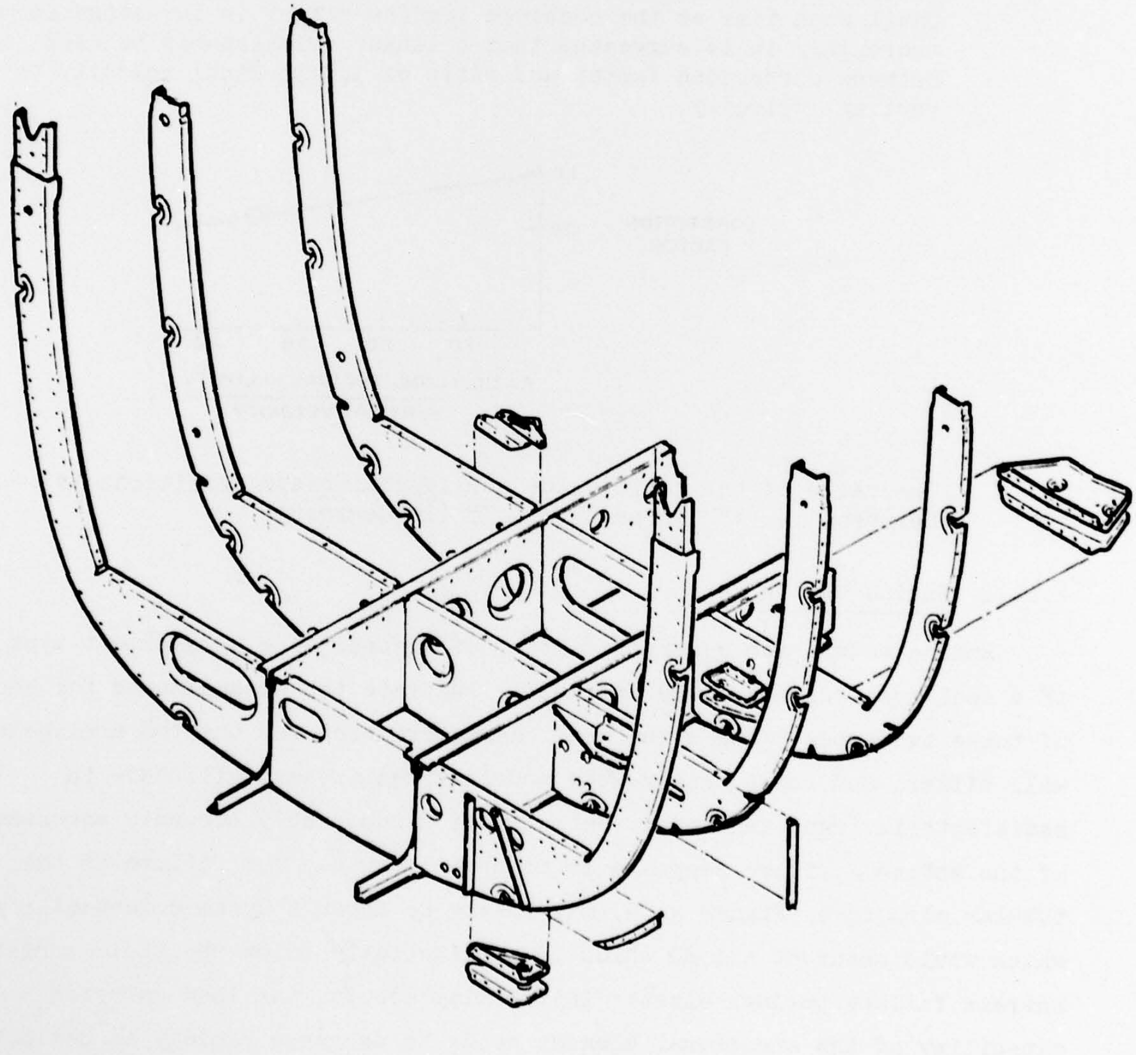
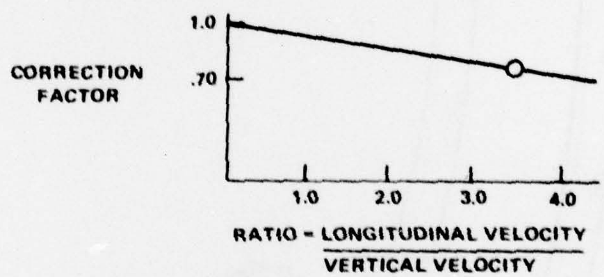


Figure 4-28. Lower Fuselage Structure for Twin Engine Low-Wing Airplane

5. The load-deflection curve for the new structure, as a first approximation is reduced or increased by the ratio of the areas. The restiffening region should be assumed to be at a length equal to 50% of the total free length.

6. Modify the load-deflection curve to account for longitudinal velocity effects. The data provided in Reference 4 is based on a pure vertical velocity up to 30 feet/second. Limited experience with this data for combined vertical-longitudinal impacts has shown that for an 88 feet/second flight path velocity and 15 degree flight path impact angle (vertical velocity ≈ 23 feet/second) a correction factor of .7 is needed to account for the longitudinal effects. Until such time as the combined loading effect is investigated more thoroughly it is suggested that a linear relationship be used between correction factor and ratio of longitudinal velocity to vertical velocity.



The range of the ratio value for typical crash conditions is between 1.4 (45 degrees) to 5.75 (10 degrees).

4.11.3 Engine Mounts

Engine mounts are generally either of a steel tube arrangement type or of a keel type. Figures 4-29 and 4-30 illustrate the arrangements for each of these two types. The structural characteristics for the two arrangements will differ; and consequently, the modeling requirement will have to satisfactorily represent their behavior if a reasonably accurate assessment of the entire airframe response is to be performed. The failure of the tubular structure (Figure 4-29) may likely be through dynamic instability which would occur at a load which is substantially below the yield stress. Wherein failure through elastic instability occurs, the load carrying capability of the structural element tends to decrease rapidly as deflection increases once the failure load has been reached. The keel mount arrangement

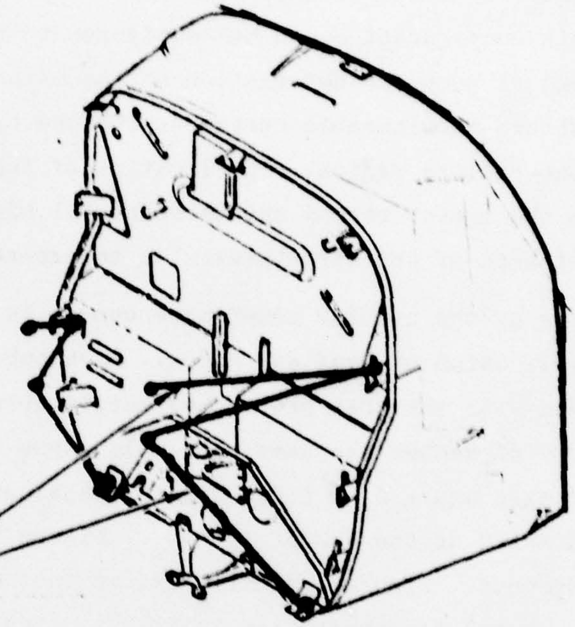


Figure 4-29. Typical Tubular Engine Mount Arrangement

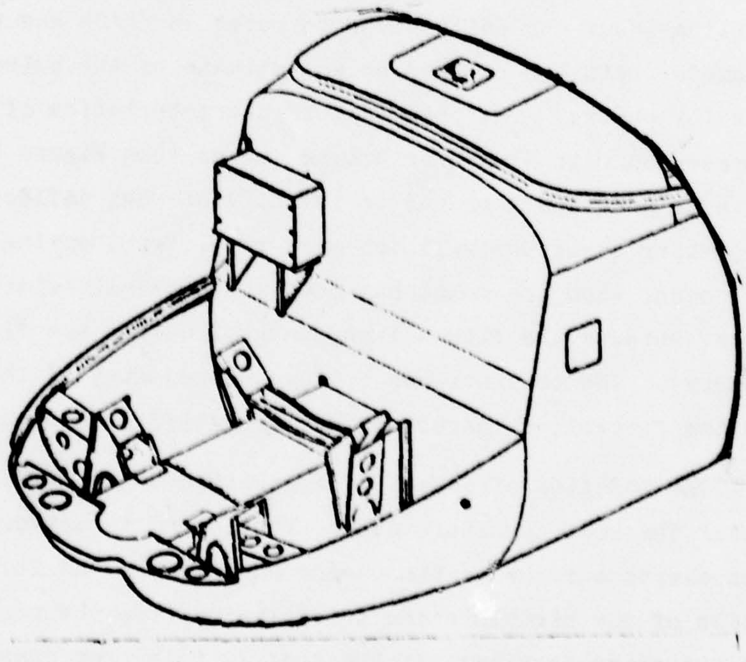
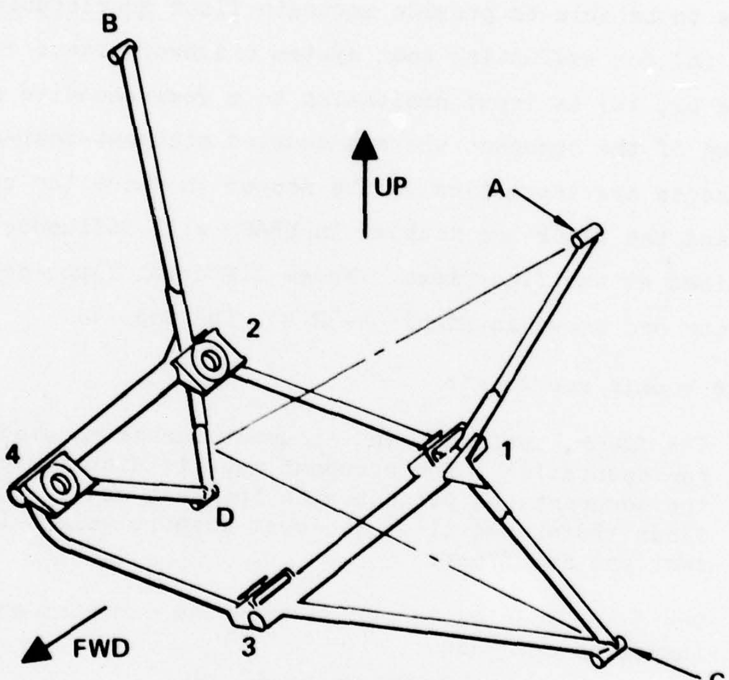


Figure 4-30. Typical Engine Keel Mount Arrangement

shown in Figure 4-30 can be expected to behave differently. The mount structure for this configuration can be considered to be an integral part of the fuselage, and as such the deformation of the structure will involve crushing that will absorb considerable energy during the plastic deformation associated with the post-failure region. The location of the two different mounts relative to the impact region and terrain will also have an influence on the loading that each of the structures will be exposed to.

Modeling of the tubular mount arrangement is straightforward in KRASH with the application of massless nodes. Each tube can be modeled as an internal beam with the area properties easily obtained for tubular sections. For this type of member the user need only input area moments of inertia about the y and z axis and a $J_x = 0.0$. The torsional stiffness factor (J_x) is then computed in KRASH as the sum of $I_y + I_z$. Figure 4-18 shows a typical tubular mount arrangement. Figure 4-31 illustrates another tubular mount arrangement (engine not shown) representation in KRASH. Area properties (area, inertia about Y and Z axis, material) are needed for members A-1, B-2, C-1, C-3, D-2 and D-4. Points 1, 2, 3 and 4 are massless nodes and are connected rigidly in KRASH to the mass of engine which is normally located at the engine cg. Buckling loads and deflections computed in KRASH and printed in the Model Parameter Data can be used as an estimate of the point at which nonlinear behavior occurs. The post-failure characteristics of the beam can be represented with NP = 8 or 9 type curves (see Figure 4-17). If a type 9 curve is used the user has to identify at what deflection the mount and supporting structure will act as a restiffened spring. Generally restiffening will occur when the mount has been substantially distorted or when the engine block contacts the firewall or protrusion from the firewall (i.e. generator, battery). The designer can review the geometry of the engine, its attachments and the firewall to ascertain where restiffening occurs.

The modeling of a keel type arrangement can be treated in one of two ways. The keel structure can be considered to act as an external spring which then exerts a force on the engine and firewall as it crushes. The characteristics of the structure can be estimated from the procedures described in the preceding section. If the keel is to be represented as an internal beam



(A) ARRANGEMENT

POINTS 1-4 ARE MASSLESS NODES

POINTS A, B, C, D ARE MASS ATTACH POINTS AT THE FIREWALL

Figure 4-31. Engine Tubular Mount Model

then a NP = 5 type curve would be most representative since a relatively large amount of crushing could be anticipated. The nonlinear deflection can be estimated from the preliminary uncoupled values computed in KRASH. For the axial direction the yield deflections are reasonably close to actual.

4.11.4 Occupant-Seat-Floor Modeling

A major consideration in the development of an **analytical** model of a crash is to be able to provide accurate floor acceleration pulses which can be used (a) for evaluating seat system crashworthiness capability by test or analysis or, (b) as input excitation to a comprehensive analytical representation of the occupant wherein coupled occupant-seat-airframe modeling requirements are impractical. The manner in which the coupled occupant-seat system and the floor are modeled in KRASH will influence the response that is obtained at the floor mass. Three different floor-seat-occupant representations are shown in Figure 4-32(a), (b) and (c).

The models represent:

- The floor, seat pan, and occupant masses modeled in a series representation. The occupant mass is distributed 44 percent with the occupant, 44 percent with the seat and 12 percent with the floor (Reference 11). The seat support weight is divided between seat pan and floor.

- The floor modeled in series with the occupant and seat masses, lumped as one mass.

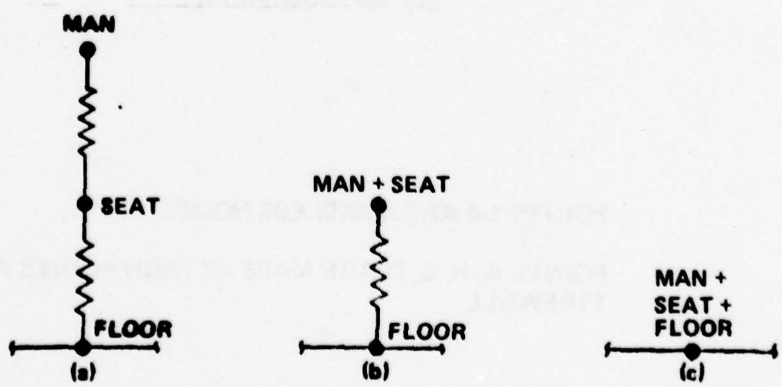


Figure 4-32. Occupant-Seat-Airframe Modeling Technique

- The masses of the occupant, seat, and floor lumped as one mass. In all three cases shown the portion of the floor mass associated with the region wherein the seat is supported is shown.

The results shown in Table 4-8 indicate that if the entire seat/man dynamic system is not modeled, but seat/man weights are lumped only at the floor, the resulting floor response is 18 percent lower than the response obtained by properly representing the dynamic behavior of the seat/man systems. These results indicate that case (a) is most desirable, but that, as a minimum, the occupant and seat should be lumped together and separated from the floor by a spring representing the seat structure (case b). The resulting analytical floor accelerations should be appropriate to use as an input pulse to a more elaborate seat/occupant response model.

Use of massless modes facilitates the modeling of seats. A typical seat configuration (Figure 4-19) can be modeled as shown in Figure 4-21. The seat and lower torso mass can be lumped together. The floor mass can be distributed at the intersections of the seat legs with the floor.

TABLE 4-8. COMPARISON OF RESULTS USING DIFFERENT OCCUPANT-SEAT-AIRFRAME MODELING TECHNIQUES

MODELING CONFIGURATION	FLOOR PEAK ACCELERATION (G)	PERCENT VARIATION
(a) floor, seat pan and occupant connected in series	58.8	---
(b) occupant and seat pan lumped together and connected in series to the floor	55.2	-6.2
(c) occupant, seat pan and floor all lumped together (no seat/man modeled)	48.3	-18.0

4.11.5 Cabin Structure

Figures 4-33 and 4-34 show the two different types of fuselage structure normally encountered in general aviation airplane structure. Figure 4-33 represents the welded tubular arrangement. Figure 4-34 shows the semi-monocoque arrangement. The welded tubular structure can be modeled almost directly since each tubular element can be represented as a beam with area properties that are directly obtainable from available data (geometry, size, material, fixity). Figure 4-35 illustrates the KRASH representation of the welded tube fuselage shown in Figure 4-33. The truss arrangements for fuselage underside and cabin top (not shown in Figure 4-35) are represented in KRASH with external springs so that potential contact with the ground is accounted for. The semi-monocoque construction typical of the fuselage shown in Figure 4-34 requires that the KRASH model represents some reasonably large sections of structure by beam elements. Figure 4-36 illustrates the KRASH model representation where element 4-5 is the aft door post, elements 6-7 and 7-8 represent the front doorpost and elements 6-9 and 7-10 represent the forward fuselage lower and upper stringers. Figure 4-37 shows the detail for the various cross sections. For each section the member in Figure 4-34 that is represented is identified. The user is required to input the following element properties for each beam: cross section area (A), area moments of inertia (I_y, I_z, J_x) material code, and stress parameters (XIQ, Z1, Z2) (see Section 2.1). The latter three terms only have significance if the user desires to monitor stresses. Wherein stress is not a factor in the analysis, it is suggested that the XIQ, Z1, and Z2 values for such beams be input as 1.0. Wherein no stress calculations are needed, the user can elect to completely bypass the stress terms by the use of one control card (Section 2.1). Whenever a beam element is used to represent complex structure, the user is advised to compute the overall axial, bending and torsional properties of the complete structural section, and assign comparable values to the model representation. This can be of particular importance in establishing the proper torsional (J_x) properties. Figure 4-38 illustrates the forward door post arrangement for the vehicle model shown in Figure 4-34. The details of the cross sections are shown in Figure 4-39.

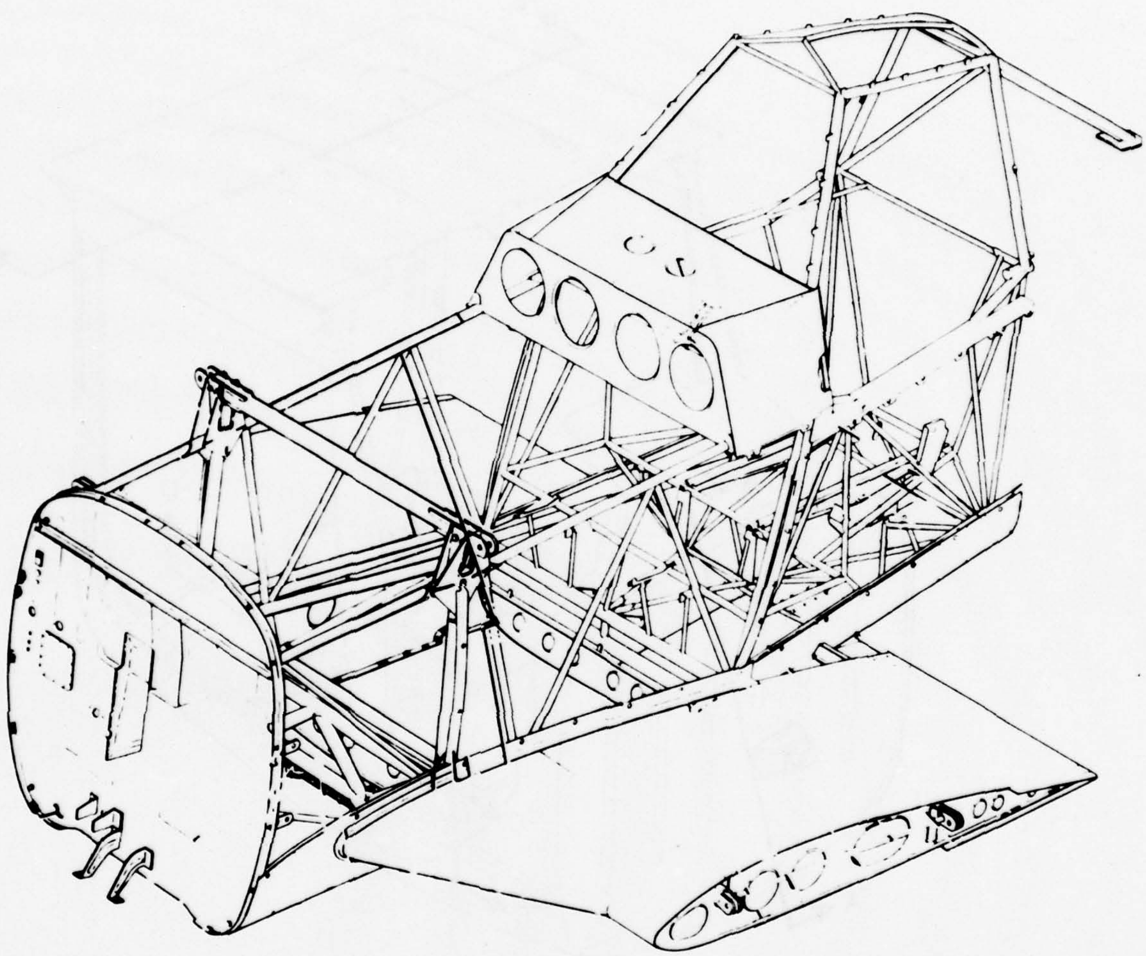


Figure 4-33. Welded Tubular Fuselage Structure

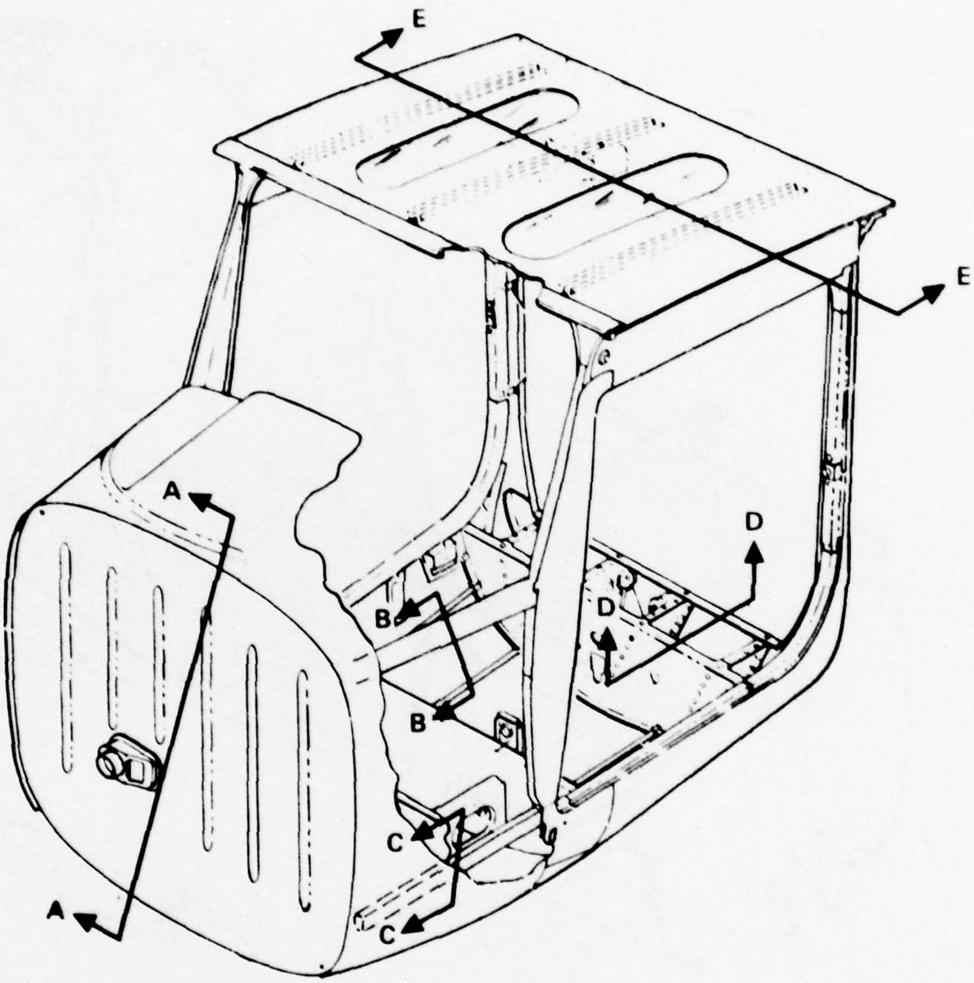
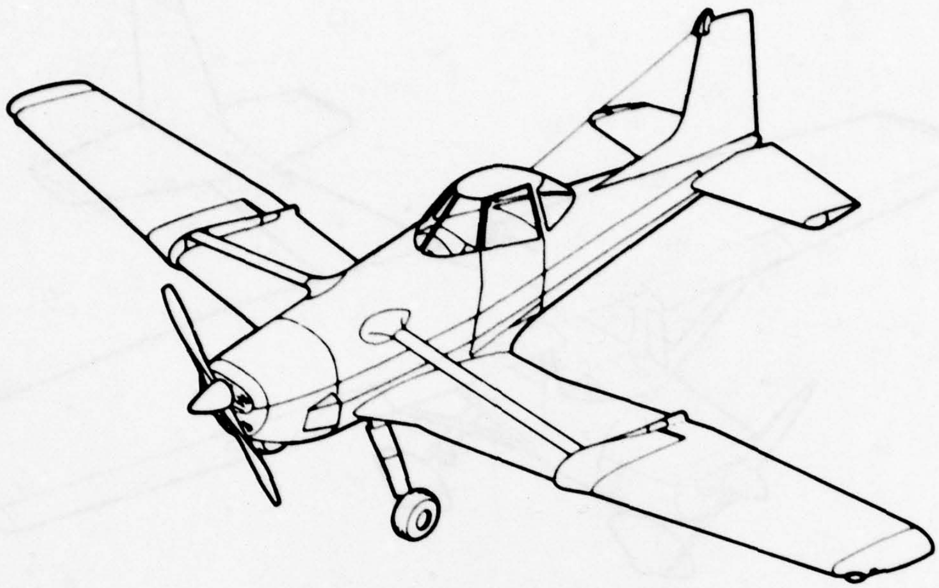
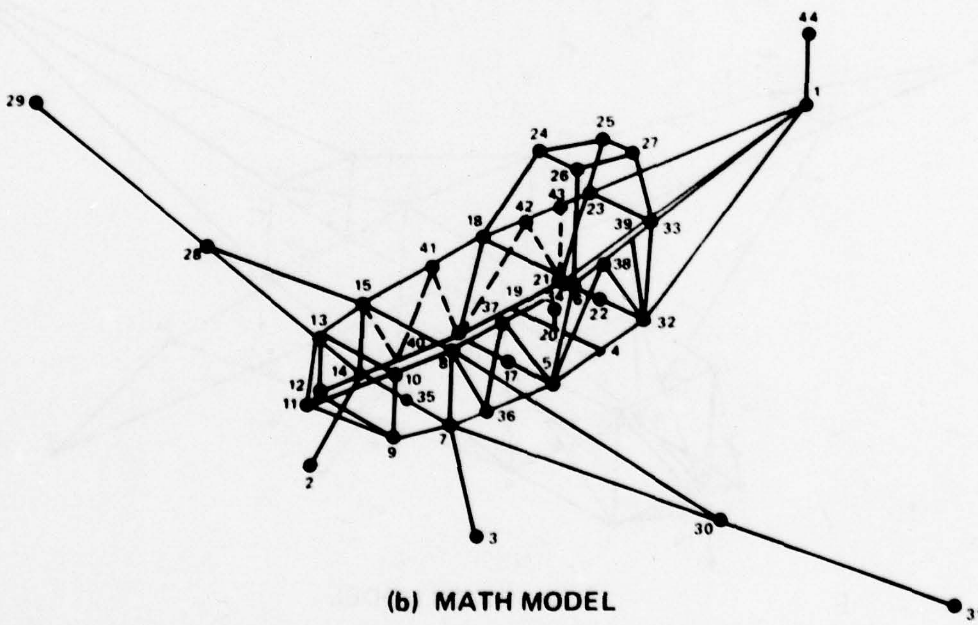


Figure 4-34. Semi-Monocoque Fuselage Section

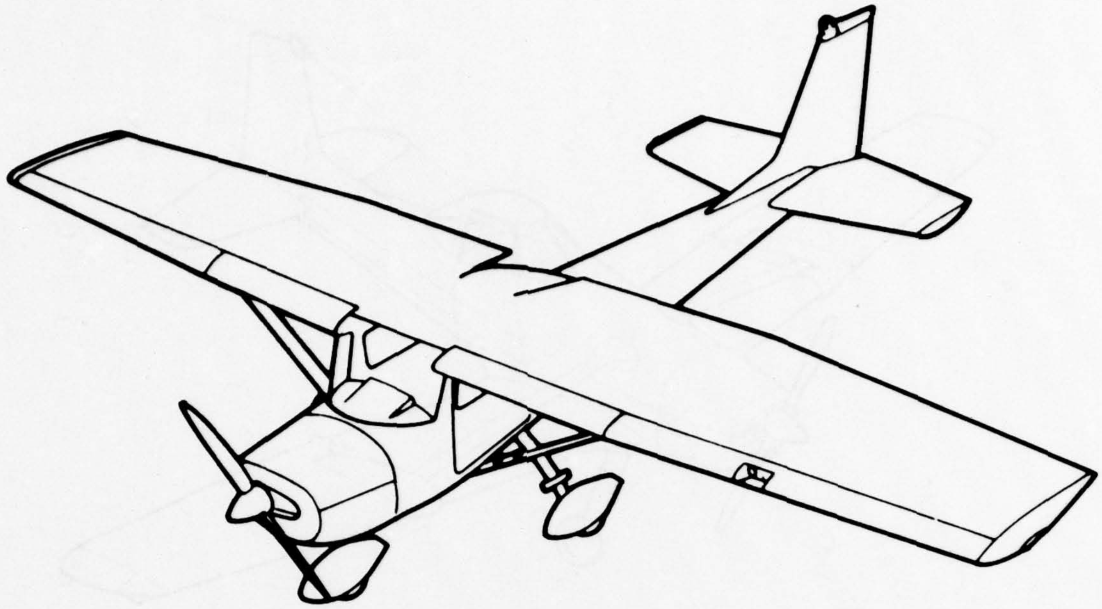


(a) OVERALL VIEW

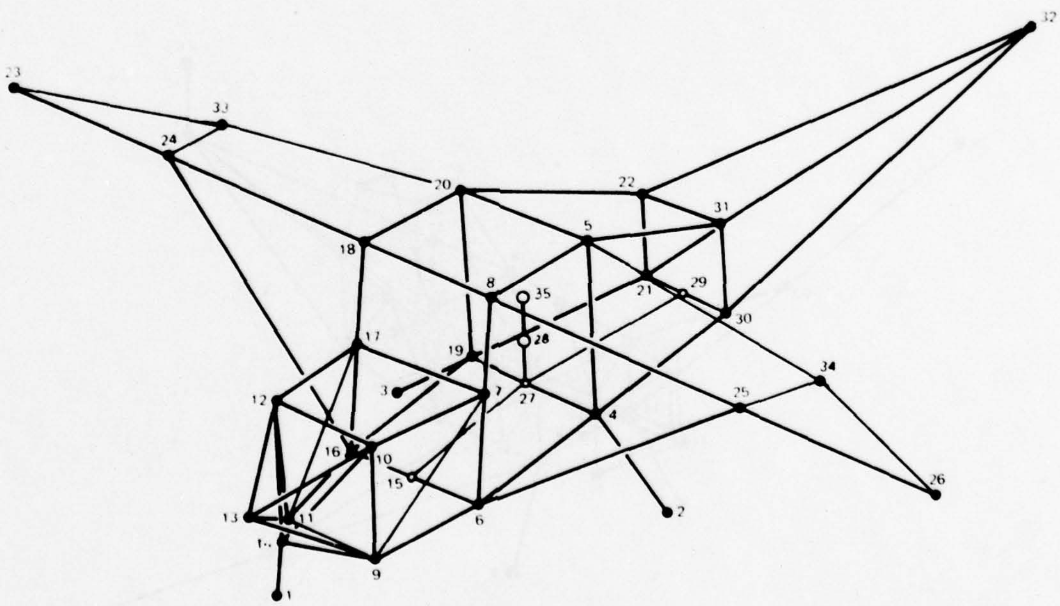


(b) MATH MODEL

Figure 4-35. Airplane With Welded Tubular Fuselage



(a) OVERALL VIEW



(b) MATH MODEL

Figure 4-36. Airplane With Semi-Monocoque Fuselage

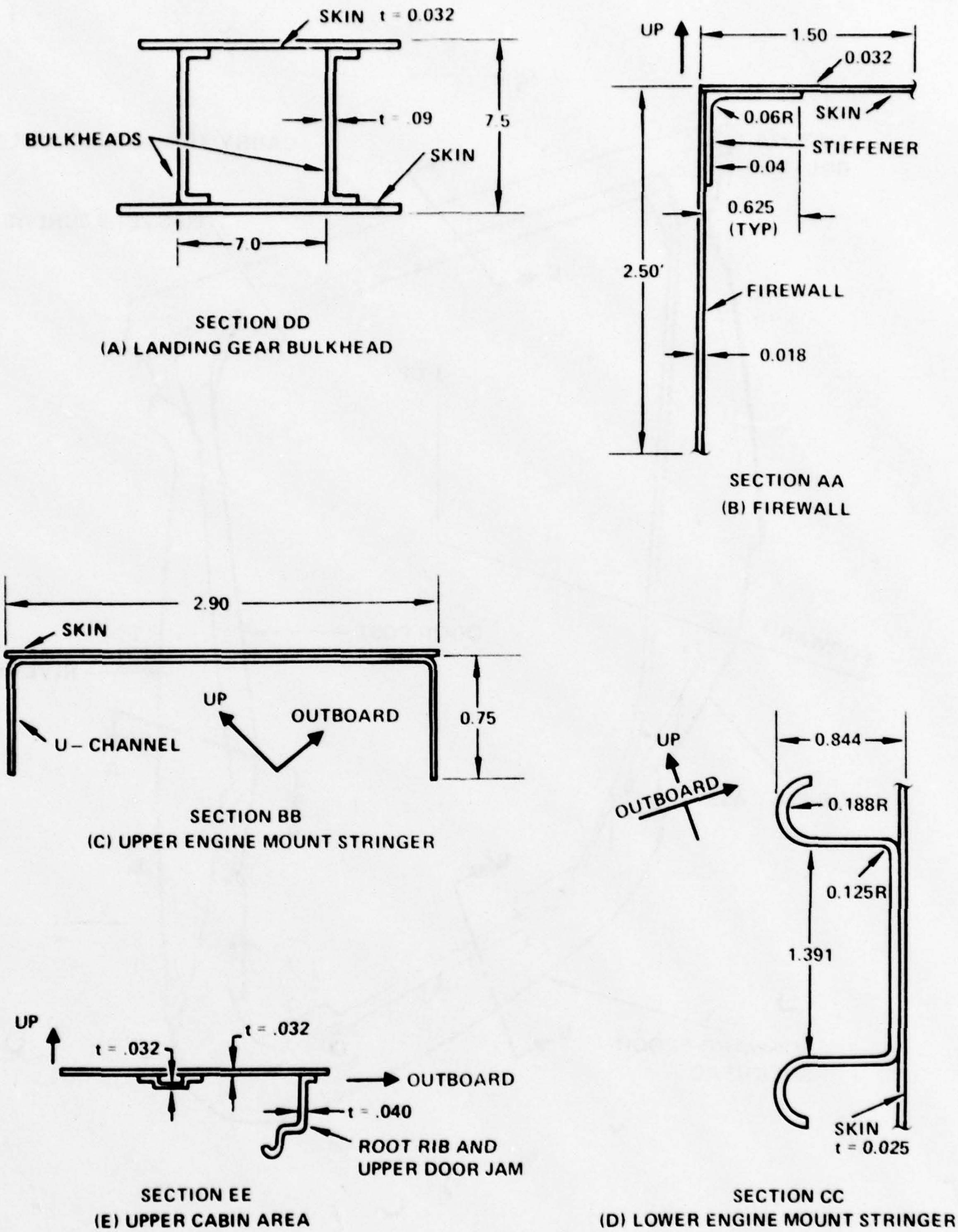


Figure 4-37. Fuselage Structure Cross Sections

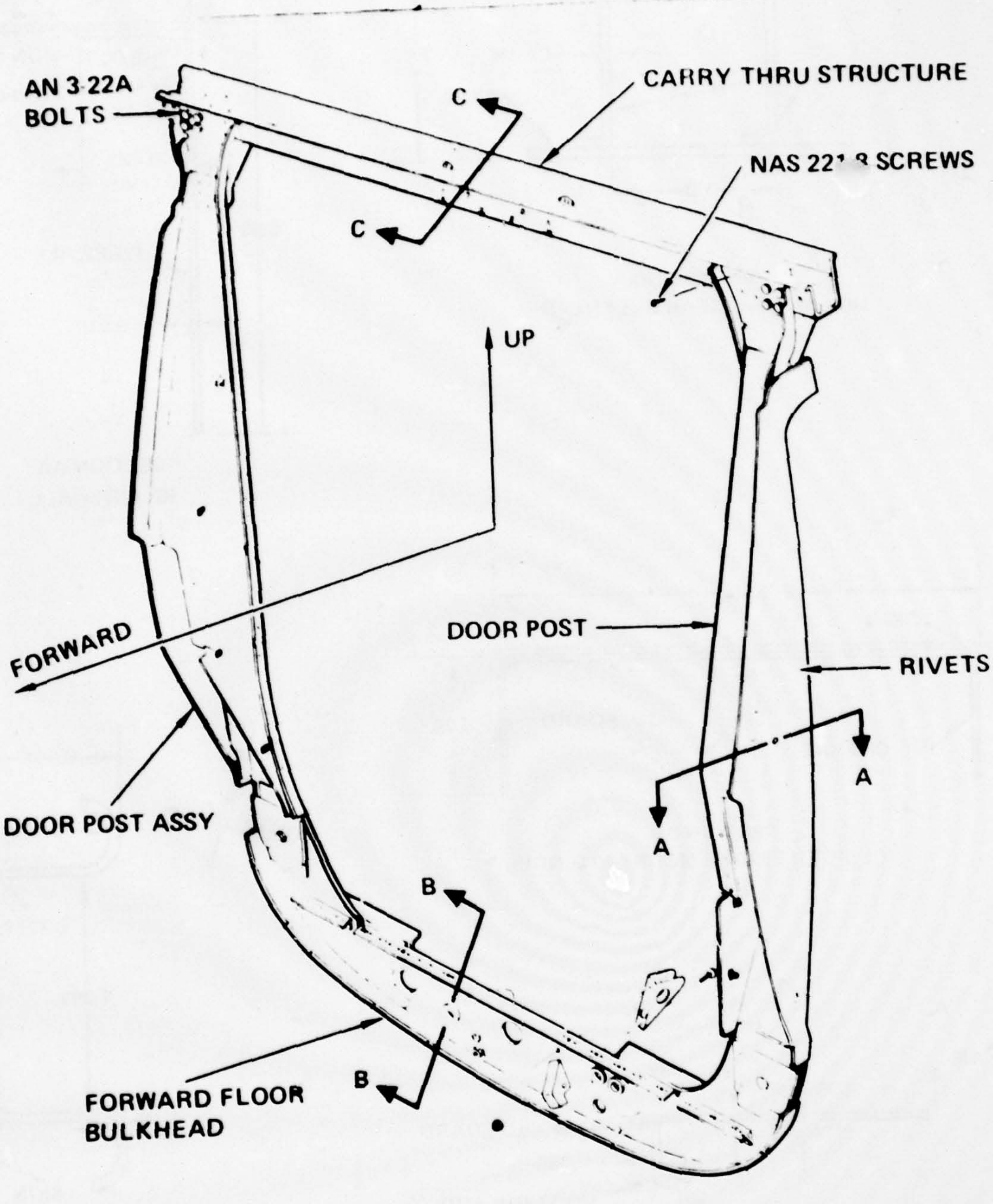


Figure 4-38. Forward Door Post, Forward Floor Bulkhead and Carry Thru Structure

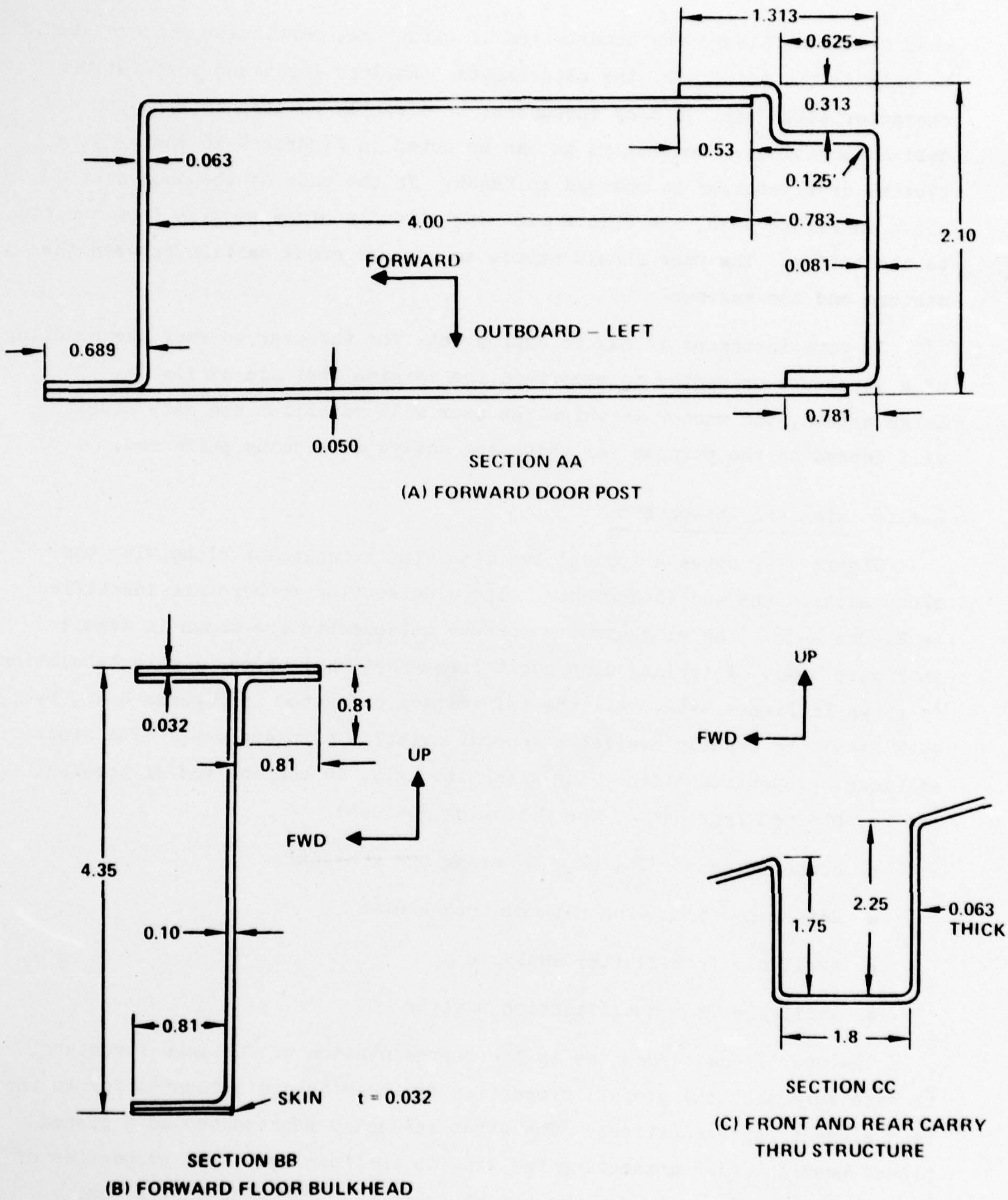


Figure 4-39. Forward Door Post, Forward Floor Bulkhead and Carry Thru Structure Cross Sections

When modeling failure characteristics of structure, particular concern should be paid to the details of the attachments. Failure loads and post-failure characteristics can, in many instances, be directly related to strength and design conditions. Generally, as can be noted in Figures 4-38 and 4-39, a typical cross section is modeled in KRASH. In the case of the door post shown in Figure 4-38, there is a wide variation in cross section from the top to the bottom. The user should select an average cross section between the minimum and the maximum.

In some instances it may be appropriate for the user to vary the modeling of a structure or region to ascertain the margins that are available. To a large extent, the manner in which the user will establish the math model will depend on the purpose for which the analysis is being performed.

4.11.6 Wing and Attachment

Figure 4-40 shows a typical two spar wing arrangement along with the cross section and end attachments. The wing section members are identified in Figure 4-36. The wing strut structure attachments are shown in detail in Figure 4-41. A typical wing strut cross-sectional property data tabulation is shown in Figure 4-42. All the information presented in Figures 4-40, 4-41, 4-42 should be readily available general aviation airplane data. The cross-sectional properties of the wing along its axis, in bending and/or torsion, can be obtained from one of the following sources:

- computation of EI_y, EI_z, GJ along the wing axis
- determined from wing natural frequencies
- available from flutter analysis
- available from qualification testing

The user is cautioned, as in the representation of fuselage structure, to make sure that the overall properties of the wing are accounted for in the beam element representations. The strut is easily represented as a pinned-pinned beam in KRASH connecting the wing to the fuselage. The properties of the strut are well defined. The end attachment of the wing at its root connecting to the fuselage is a pinned-fixed element (Section 2.1).

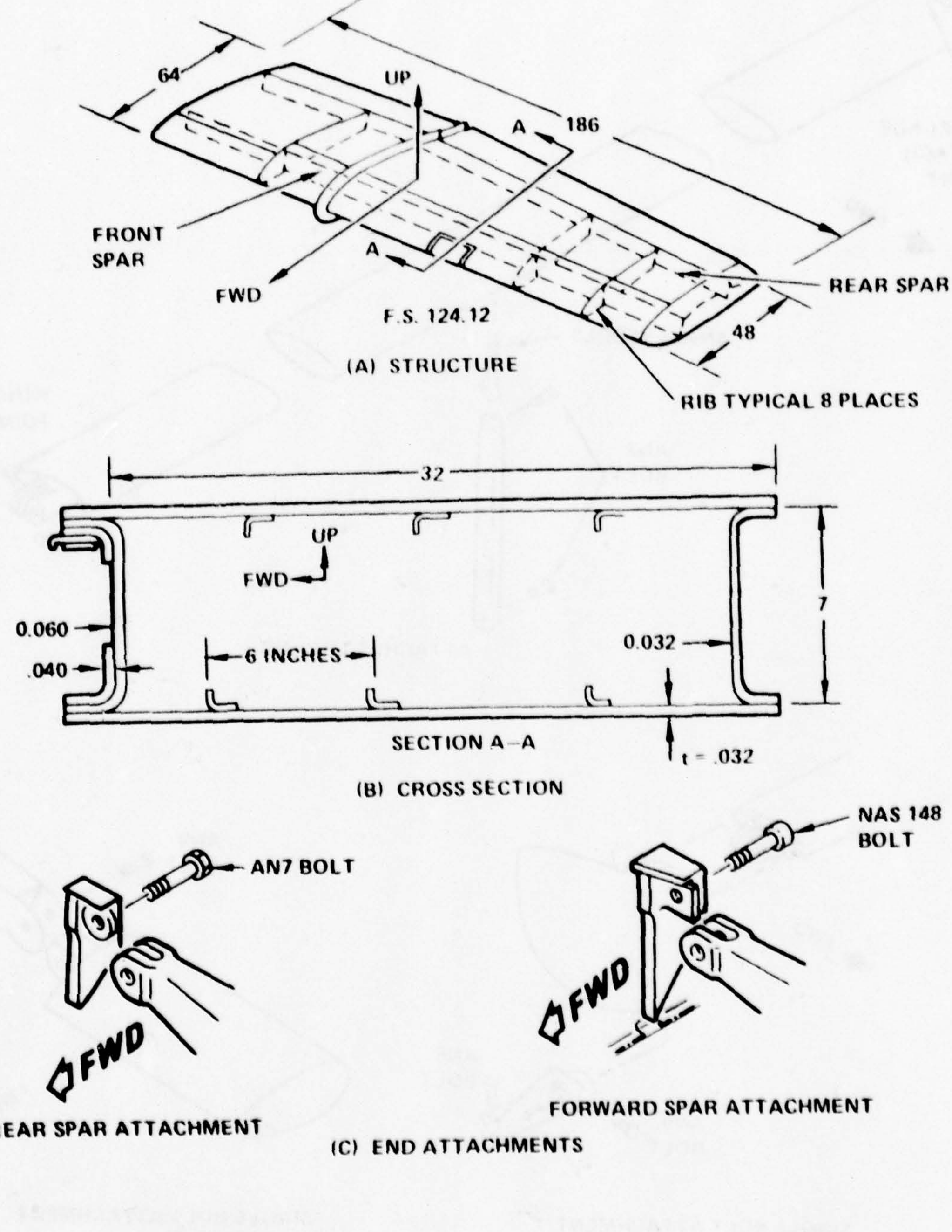


Figure 4-40. Wing Structure, Cross Section and Attachments

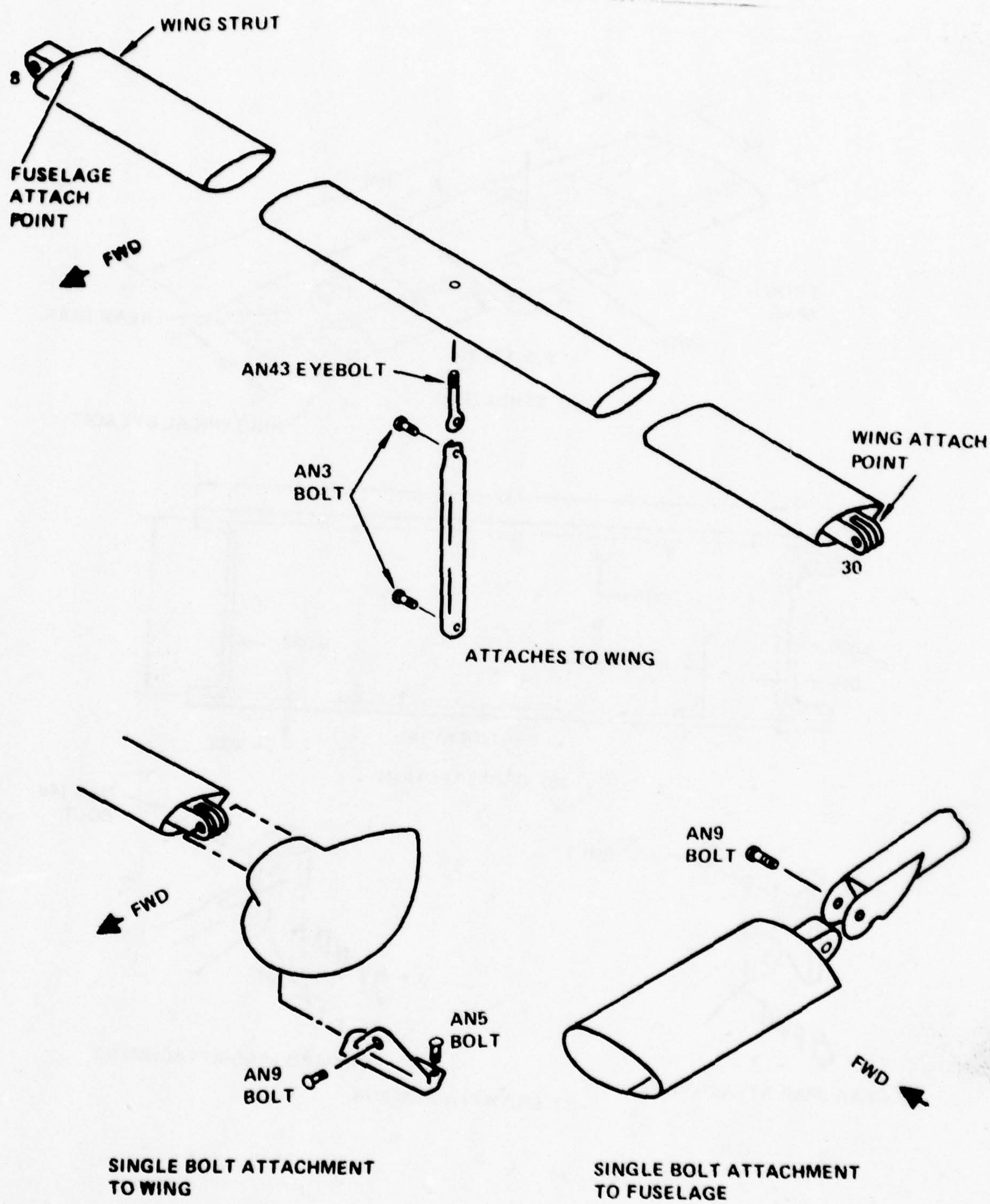
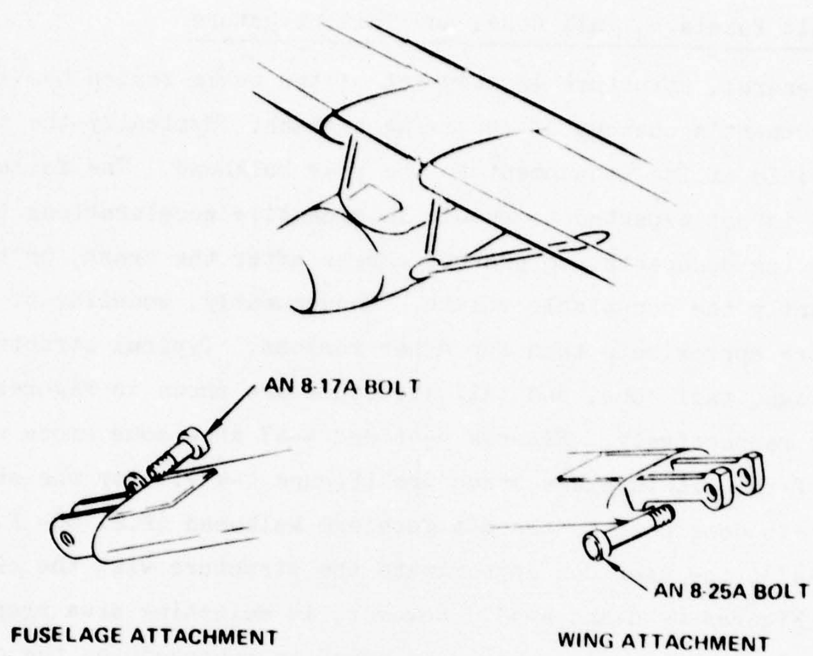
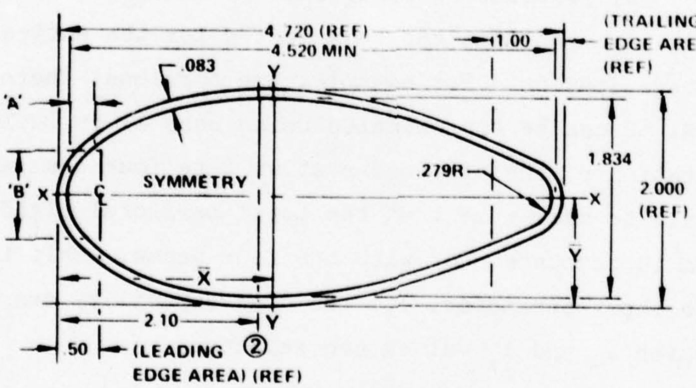


Figure 4-41. Low-Wing Airplane Wing Strut Structure and Attachments



(A) WING STRUT



'A'	'B' MIN
.255	.955
.825	1.565
3.040	1.470
3.755	1.070

AREA SQ. IN.	$\bar{X}$	$\bar{Y}$	I_{XX}	I_{YY}	WEIGHT LBS. PER 100 IN.
.897	2.27	1.0	.4645	1.8686	8.97

(B) WING STRUT CROSS SECTION

Figure 4-42. High-Wing Airplane Wing Strut Structure Attachment and Cross Section

4.11.7 Aft Fuselage, Tail Cone, and Tail Structure

In general, structure located aft of the cabin region has little bearing on the occupant's chances of surviving a crash. Typically the tailcone will fail or yield at its attachment to the rear bulkhead. The failure of this structure is not expected to result in excessive accelerations being transmitted to the occupants, to prevent egress after the crash, or to reduce significantly the occupiable volume. Consequently, modeling of this structure can be more approximate than for other regions. Typical structure for the aft fuselage, tail cone, and tail structure are shown in Figures 4-43, 4-44 and 4-45, respectively. Figures 4-46 and 4-47 show some cross section details of the aft fuselage structure (Figure 4-43). For the structure from the aft door post to the aft fuselage bulkhead (F.S. 60- F.S. 95, Figure 4-43), the user can approximate the structure with the cross sections shown in Figures 4-46 and 4-47. However, in selecting area properties consideration, once again, should be given to representing the overall axial, bending and torsional behavior of a region. For example, with the use of Table 4-6, a torsional constant can be selected for the entire cross section at a given fuselage station. For example, the torsional factor for the aft door post at F.S. 60 can be approximated using case 11 in Table 4-6. The actual representation of the aft door post will be four beam elements. Thus, the user will have to make sure that the total torsional rigidity for the complete section is accounted for with the four beams. This is easily controlled with the input parameter, J_x. Bending capability can be treated in the manner in which I_y and I_z values are selected.

For the tail cone and tail section it is suggested that a plot of AE, EI_y, EI_z, GJ versus length (tailcone), versus height (vertical tail), and versus lateral distance (horizontal tail) be computed.

Generally the stiffness of the horizontal tail is not needed since one mass point along the airplane centerline can represent the complete tail section. However if the vertical and horizontal tails are combined the total mass should be properly represented with regard to inertias and location. The beam members representing these sections should

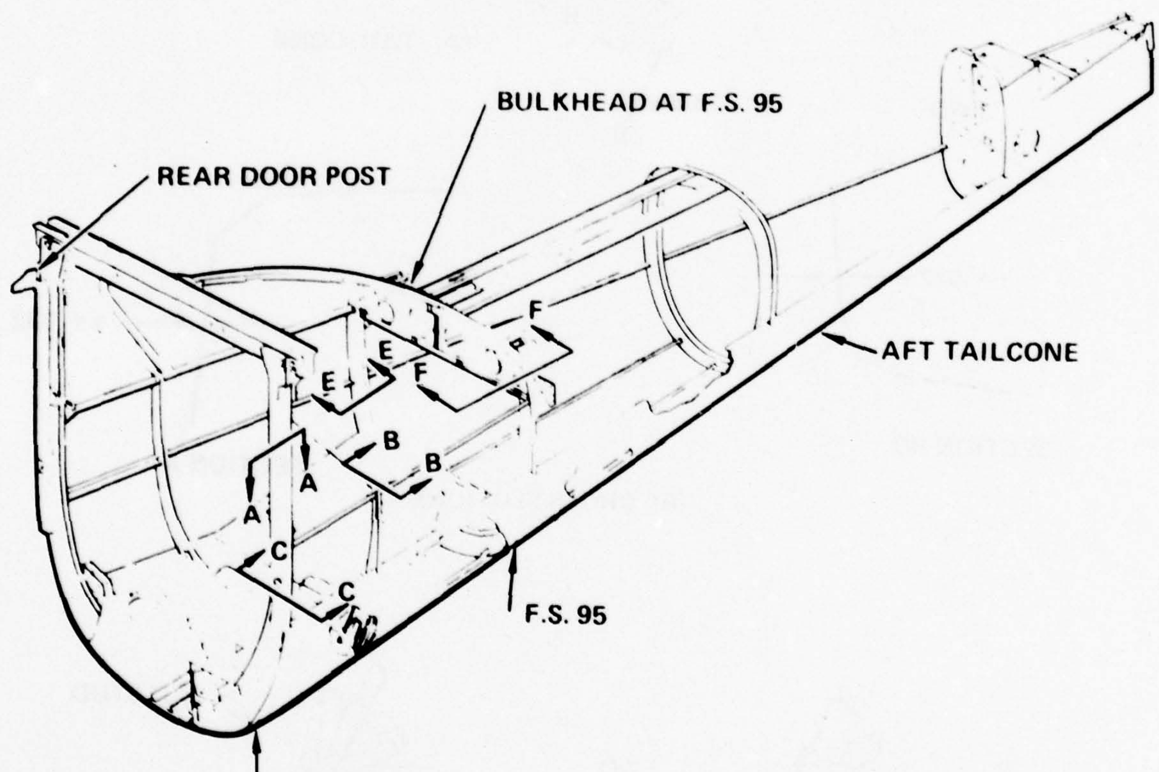


Figure 4-43. Aft Fuselage Structure

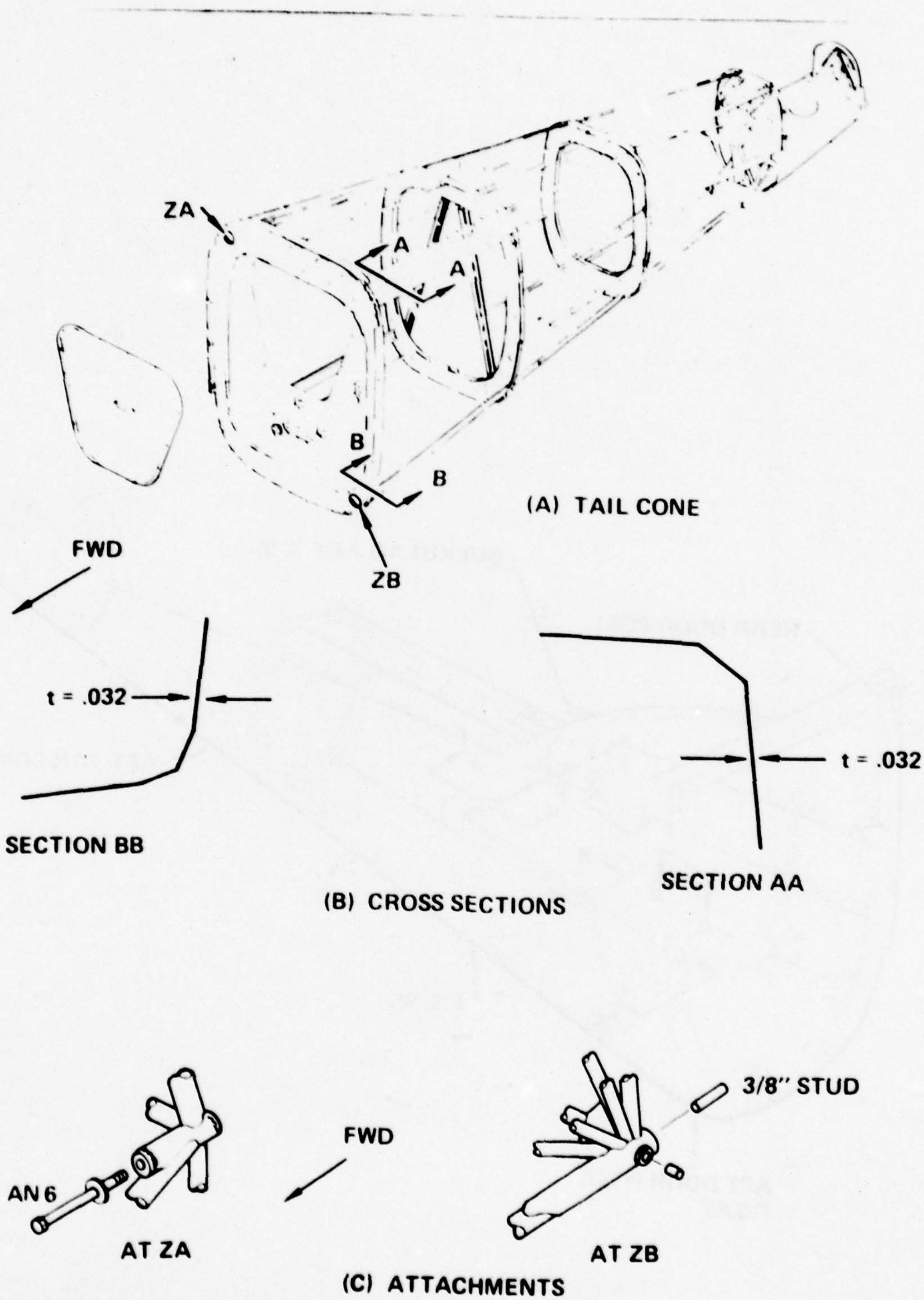


Figure 4-44. Fuselage Tail Cone, Cross Section and Attachments

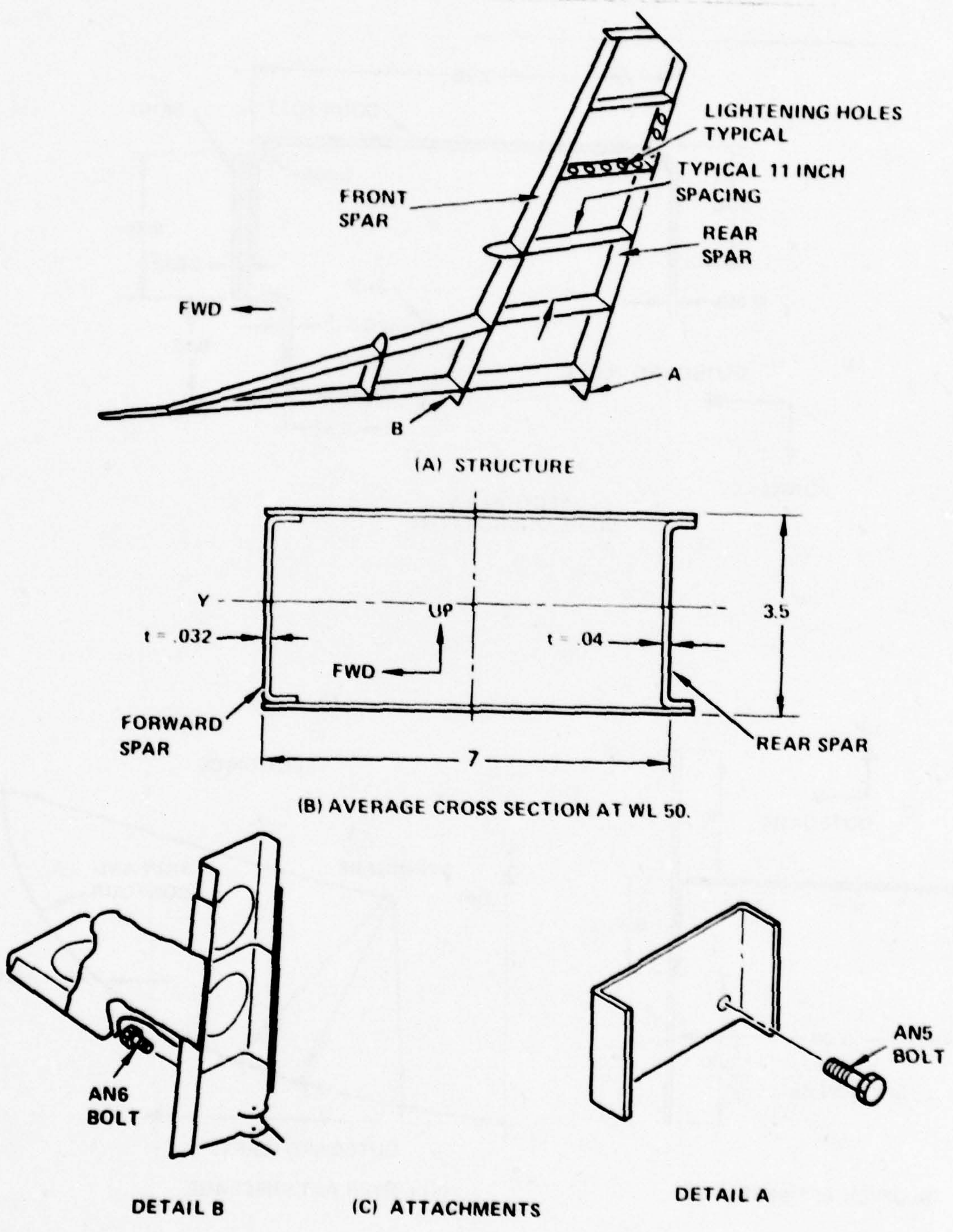


Figure 4-45. Vertical Tail Structure, Cross Section and Attachments

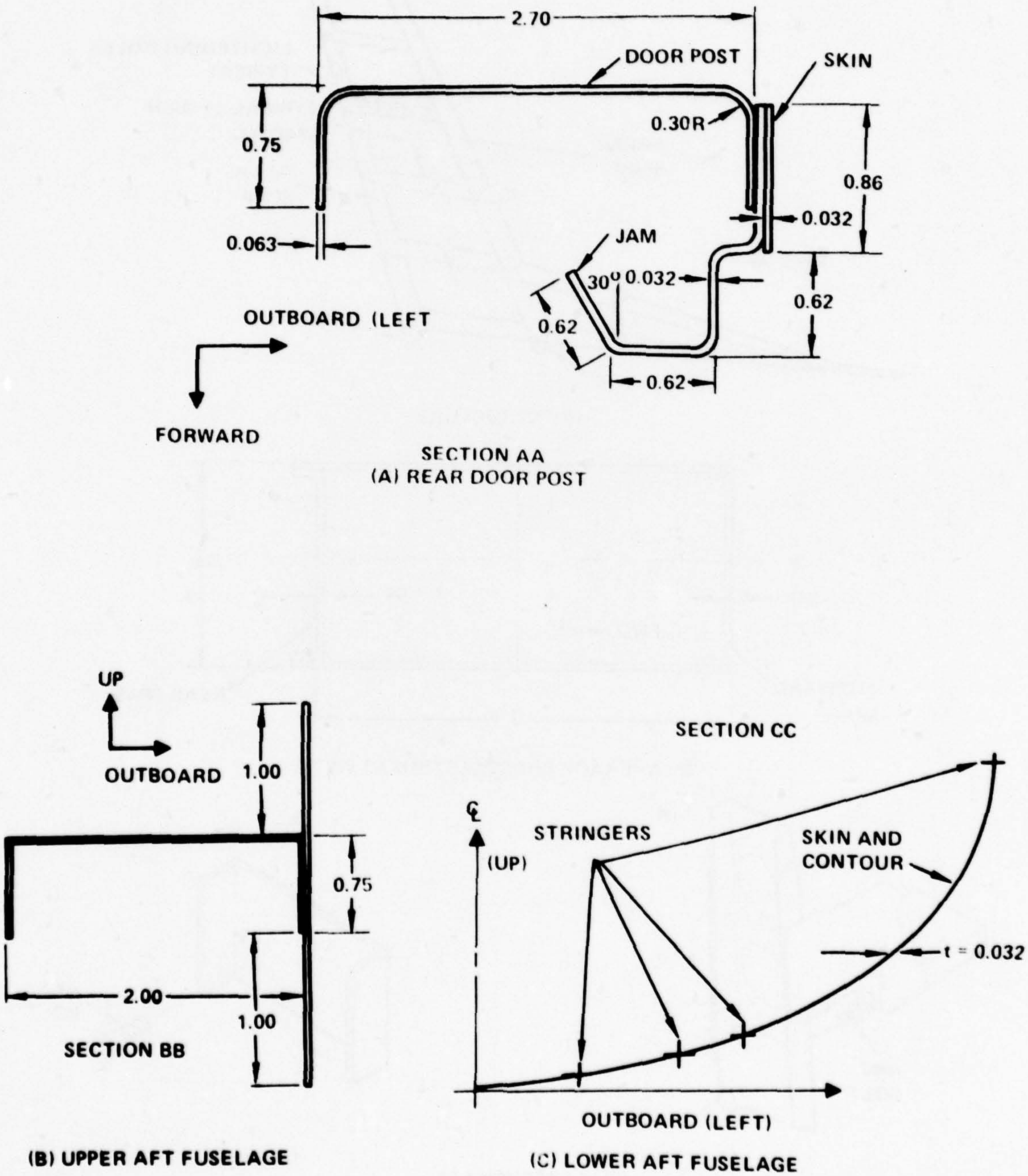


Figure 4-46. Aft Fuselage Structure Cross Sections

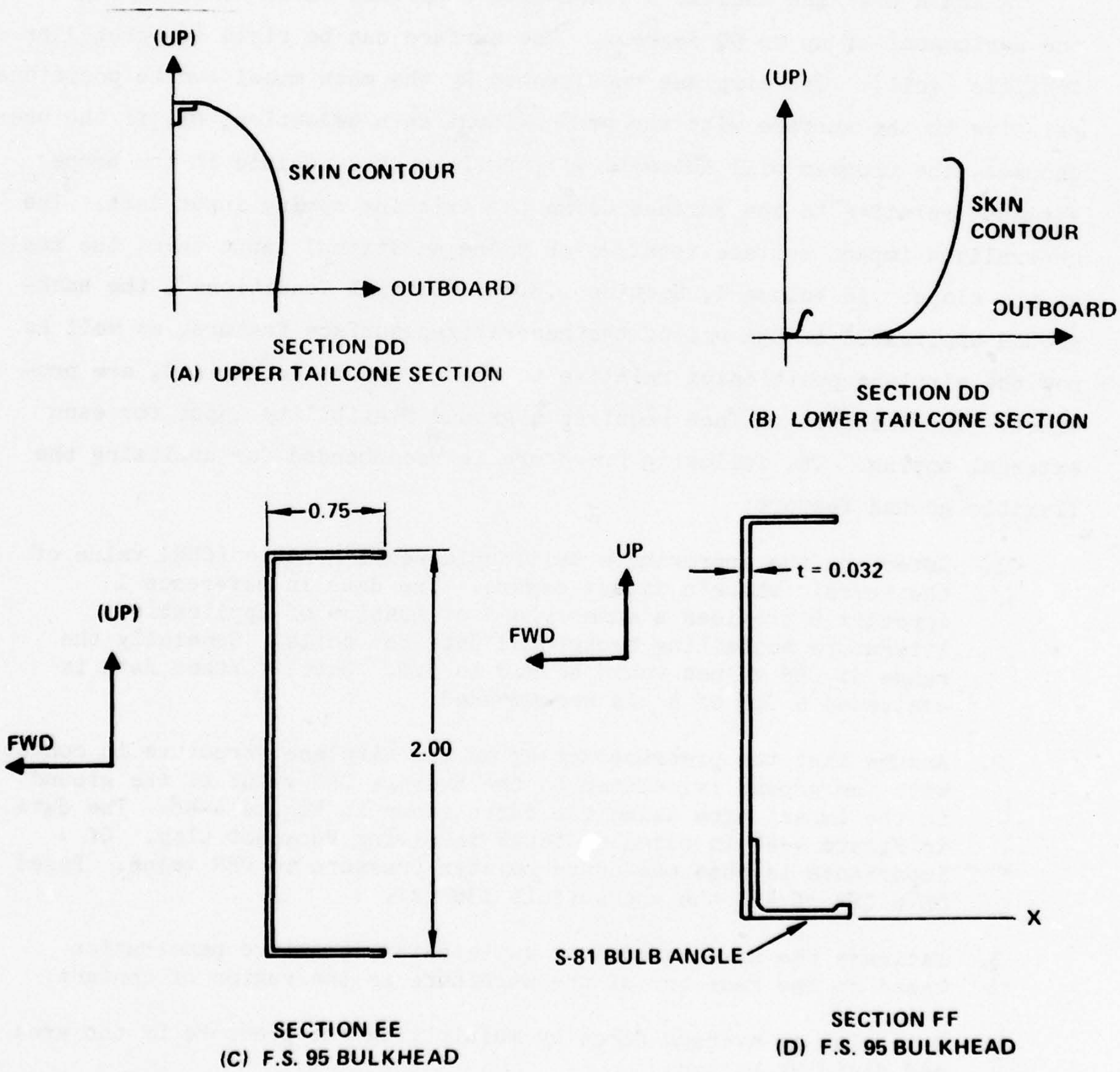


Figure 4-47. Tail Cone and F.S. 95 Bulkhead Structure Cross Sections

then contain the overall characteristics of an average section. For example, the axial capability can be shared by each member in proportion to the cross-sectional area associated with the respective members. Similarly, the overall bending and torsional properties must be represented.

4.12 TERRAIN

A KRASH user can analyze a crash onto a surface which makes an angle with the horizontal of up to 90 degrees. The surface can be rigid (concrete) or flexible (soil). The airplane represented by the math model can be positioned relative to the surface with the proper input data selection, or, if the user chooses, the program will automatically position the vehicle in the proper attitude relative to the surface using the existing spring input data. The generalized impact surface requires only one additional input term, the angle of the slope. In Volume I, Section 1.3.15, "Initial Conditions", the background applicable to the use of the generalized surface feature, as well as how the airplane positioning relative to the ground is determined, are provided. The flexible surface requires a ground flexibility input for each external spring. The following procedure is recommended for utilizing the flexible ground feature:

1. Determine the approximate California Bearing Ratio (CBR) value of the terrain wherein impact occurs. The data in Reference 1 Appendix B provides a summary and evaluation of applicable literature containing background data for soils. Generally the range of CBR values would be 2.0 to 5.0. Until further data is evaluated a CBR of 4 is recommended.

2. Assume that the pressure acting on the airplane structure in contact with the ground is related to the average CBR value of the ground in the impact area using the curve shown in Figure 4-48. The data in Figure 4-48 is based on tests involving Buckshot Clay. Of importance is that the curve relates pressure to CBR value. Based on a CBR of 4.0 the pressure is 136 psi.

3. Estimate the maximum area of anticipated structure penetration based on the geometry of the structure in the region of contact.

4. Determine an average force by multiplying the pressure by the area and dividing by two.

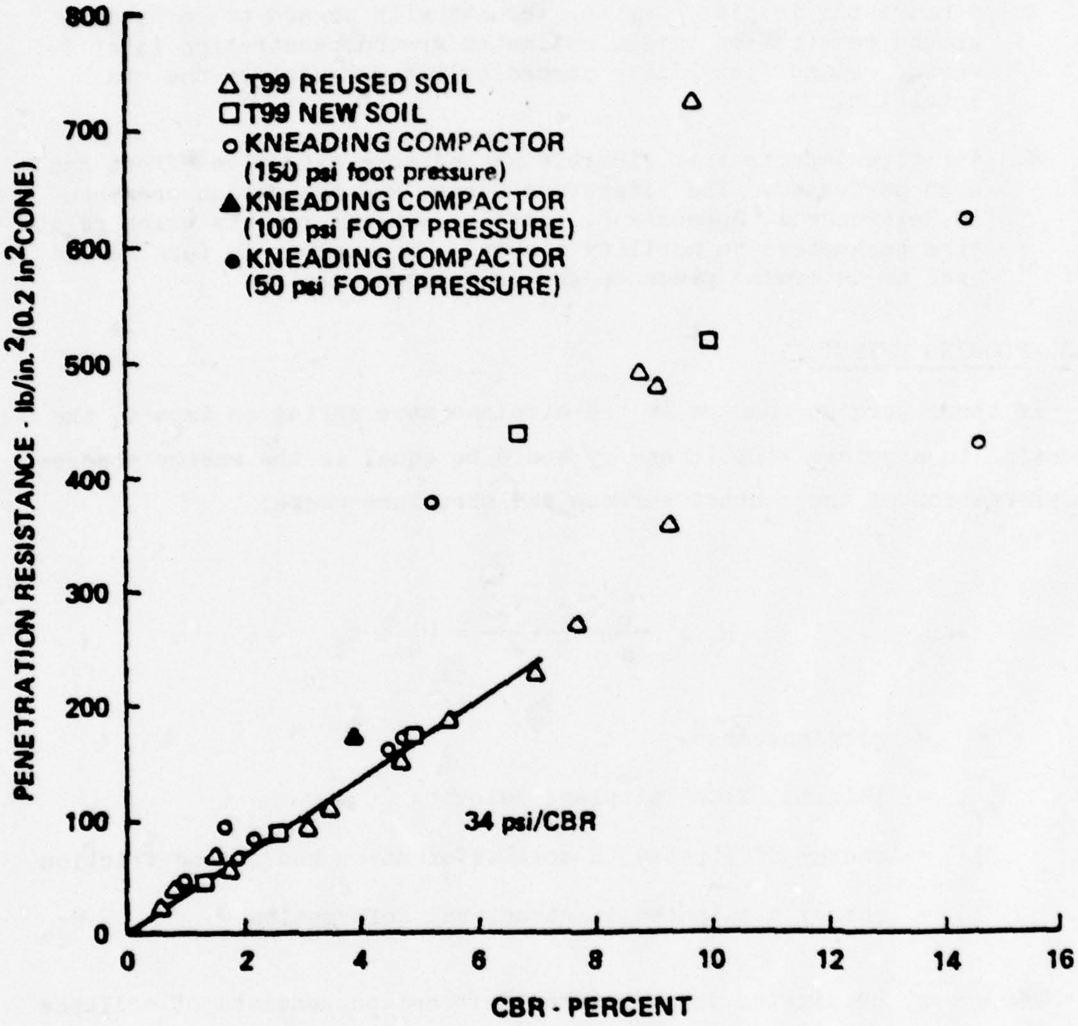


Figure 4-48. Relationship of Airfield Cone Penetration Resistance to CBR on Buckshot Clay (Reference 13)

5. Obtain an initial trial ground flexibility by dividing estimated ground penetration by the average force. Input the resultant flexibility (in/lb), into the program.

6. Select a ground coefficient of friction for a flexible ground analysis. The ground coefficient of friction should be between 1.0 and 1.5. Normally for impacts on concrete surface the ground coefficient of friction is taken as .40.

7. Compare the initial computer results with regard to computed ground penetration versus estimated ground penetration (step 5). Revise ground flexibility accordingly and reanalyze the crash condition.

8. For tire impacts into flexible ground more extensive effort has been performed. The Literature Survey and Evaluation presented in Reference 1, Appendix B, contains several reports which relate tire parameters to mobility number. This number in turn can be used to determine pressure and ground penetration.

4.13 PLOWING EFFECT

If there were no changes in the airplane mass during an impact, the reduction in airplane kinetic energy would be equal to the energy absorbed by deformation of the contact surface and structure where:

$$M_A \times \frac{V_o^2 - V_f^2}{2} = U_G + U_S$$

M_A = airplane mass

$V_{o,f}$ = initial, final airplane velocity

U_G = energy dissipated in soil deformation and ground friction

U_S = energy dissipated in structural deformation

The energy dissipated in structural deformation consists of collapse of structure forward of the cabin and deformation of the cabin and other structure. Consequently, the amount of energy absorbed by the contact surface (U_G) can influence the amount of energy needed to be absorbed by airframe deformation. Scooping of earth is also important because, as the effective

mass of earth is accelerated, the forces are imparted to the airplane. This effect can be significant since the deceleration of the airplane varies with the velocity squared. However, modeling of this effect in KRASH depends greatly on the amount and type of data that is available. For example, Figure 4-49 (obtained from Reference 8) shows a family of curves relating impulsive airplane acceleration to the ratio of effective earth mass to airplane mass for various impact velocities.

Earth scooping phenomena can be modeled by calculating a scooping force using conservation of linear momentum. It is assumed that a given mass of earth is scooped up and becomes part of the vehicle. To maintain constant momentum, the vehicle/dirt combination must slow down. Equating the impulse from the scooping force to the change in momentum, we obtain

$$F_{scoop} = \left(\frac{K}{1 + K}\right) \frac{V}{\Delta t}$$

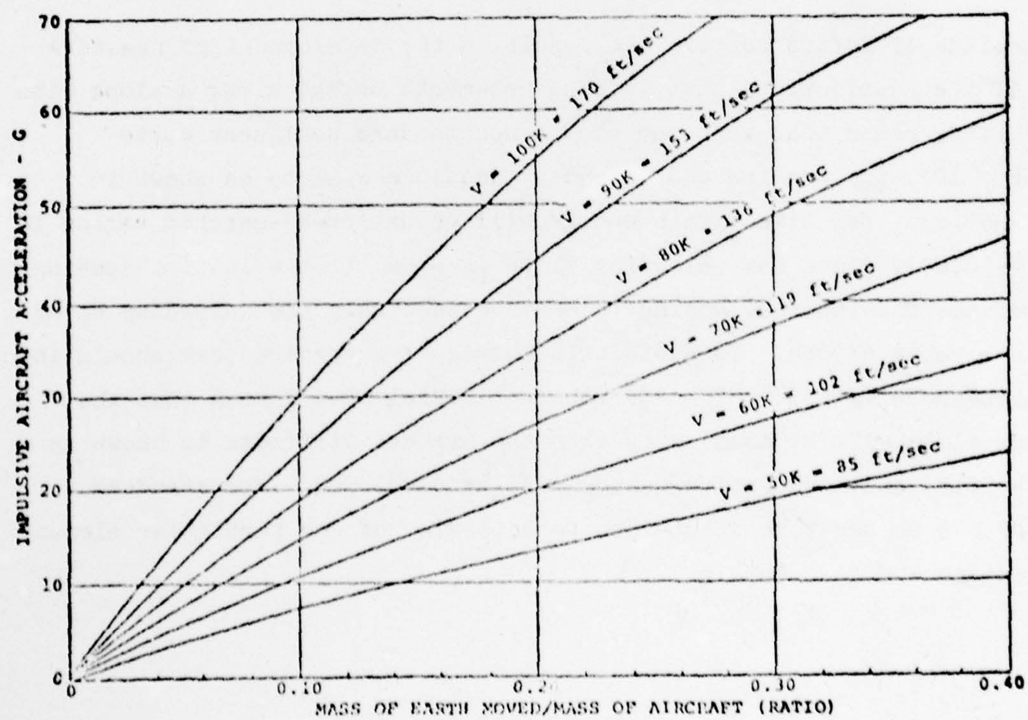


Figure 4-49. Impulsive Aircraft Acceleration as a Function of Velocity and Ratio of Accelerated Mass of Earth to Aircraft Mass (Reference 8)

where $K = M_{earth}/M_{airplane}$ is the ratio of the earth mass scooped up to the airplane mass. V is the airplane forward velocity and Δt is the time period over with F_{scoop} acts. K and Δt are input constants. F_{scoop} is applied directly to one or more specified lumped masses as an additional external force. The energy balance equations are modified to include the energy due to F_{scoop} acting on the airplane.

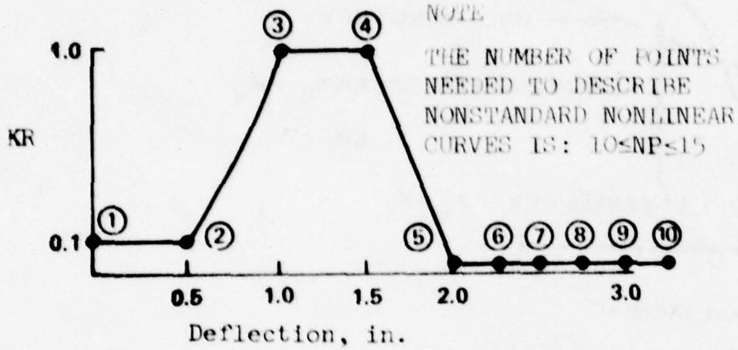
4.14 MODELING PROBLEMS

The major types of problems that a user of KRASH can encounter are the occurrence of negative strain, energy growth (to an untolerable level) and instability.

Negative strain energy can occur during the analysis when member load-deflection characteristics have reached the nonlinear region and/or the members have started to unload. Review of the energy output summary will generally provide the necessary information to detect the source of this problem.

Modeling of soft structure can result in the development of negative strain if the user forgets that internal elements unload along a slope with KR = 1. This means that when one uses a nonstandard nonlinear curve ($15 > NP > 10$), the loading and unloading sequence will be as shown in Figure 4-50(a). Negative strain energy will occur (cross-hatched region in Figure 4-50(a)), since the unloading slope is equal to the initial loading slope because the internal coding in KRASH establishes the unloading KR as equal to a value of one. To avoid this source of error the user should input the nonlinear curve ($15 > NP > 10$) with an initial KR < 1 such that the unloading slope will be associated with the highest stiffness as shown in Figure 4-50(b) and no negative energy will be developed. For standard curves $NP \le 9$ no negative strain due to unloading of one particular element and direction should occur.

The type of load-deflection curve described represents a combination of a soft spring mounted to hard structure (i.e., engine mount attached to a Keel beam). The typical KR versus deflection input data required to model this type of structure to prevent negative energy is shown below:

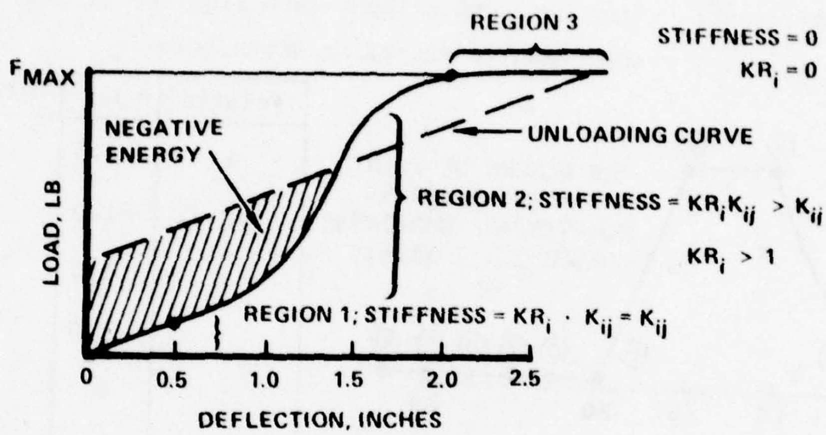


Point(s)	≪ KR	Deflection
1	≪1.0	0
2	≪1.0	0.5
3	1.0	1.0
4	1.0	1.5
5	0	2.0
6 - 10	0	>2.0

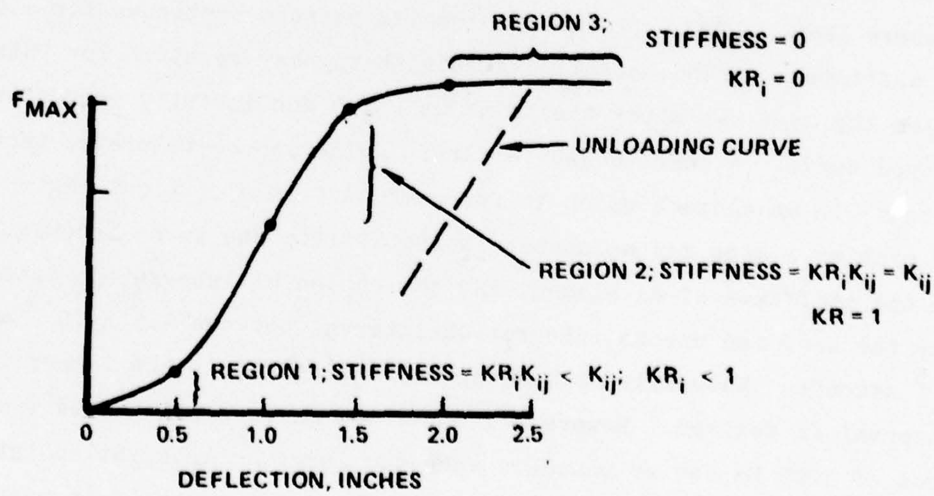
Negative strain energy can also occur with the standard KR curves under certain conditions of coupled bending in the nonlinear region. This can occur when one of the coupled beam degrees-of-freedom is unloading into the nonlinear region where KR=0. If this loading/unloading pattern continues for a continuous and sufficient period, negative strain energy may result. For this type of problem the user can alter the point at which nonlinearity occurs or change the KR type curve. A small negative strain value can be tolerated particularly if it occurs in an element which is far removed from a critical region. Another problem a user may encounter is instability due to an incompatibility between the stiffness of an element and the choice of integration internal. Normally the user can use an integration interval between 1.5×10^{-5} and 3×10^{-5} seconds. Naturally from economic considerations the larger integration interval is desired. However, short stiff members which have frequencies in excess of 1000 Hz can go unstable when too large an integration interval is used. The effects of such an instability will manifest itself in unexpected ruptures, excessive oscillatory motion and/or too large an energy deviation from the norm (100 percent). The user, to rectify this problem has two alternatives;

(1) Revise the model and eliminate stiff members, if practical.

(2) Reduce the integration interval.



(a) Negative Strain



(b) Positive Strain

Figure 4-50. Internal Member Unloading; Negative and Positive Strain Energy

SECTION 5

TYPICAL MODEL ARRANGEMENTS

The manner in which an airplane is modeled in KRASH depends to a large extent on the crash environment that is being considered. As noted in earlier portions of Section 3, the approximate techniques employed in and with KRASH are based on representing structural behavior to obtain gross vehicle behavior. The more critical the region of concern the more care in modeling the structure is required. Conversely, the less consequence that certain structure behavior has on occupant survival, the more approximate the representation of that structure can be. In general, it is anticipated that the primary crash conditions for light fixed-wing general aviation airplanes will involve frontal impact with an impact angle at or less than 45 degrees, and with roll and yaw angles within ± 15 degrees. Accident types that will influence the formulation of the mathematical models consist of a (1) stall condition, (2) high speed, low attitude impact and overturn, (3) high speed, high angle of impact and (4) high rate of descent, nose up attitude, initial impact on landing gear and/or mid fuselage. While the details of the structure that are being represented depend on the actual vehicle for which the analysis is being performed, there are general guidelines as to size requirements depending on the type of airplane that is being modeled. The size of the math model that has to be developed indicates to the user the extent of the data that may be required to adequately model an airplane, the regions where emphasis and more detail would be desirable, the potential cost of performing an analysis and the critical areas wherein increased energy absorption and improved crashworthy features may be most beneficial.

5.1 SINGLE-ENGINE, LOW-WING AGRICULTURAL AIRPLANE

Figure 5-1 shows an overview of a typical single-engine, low-wing airplane whose major purpose is to perform agricultural functions. This airplane

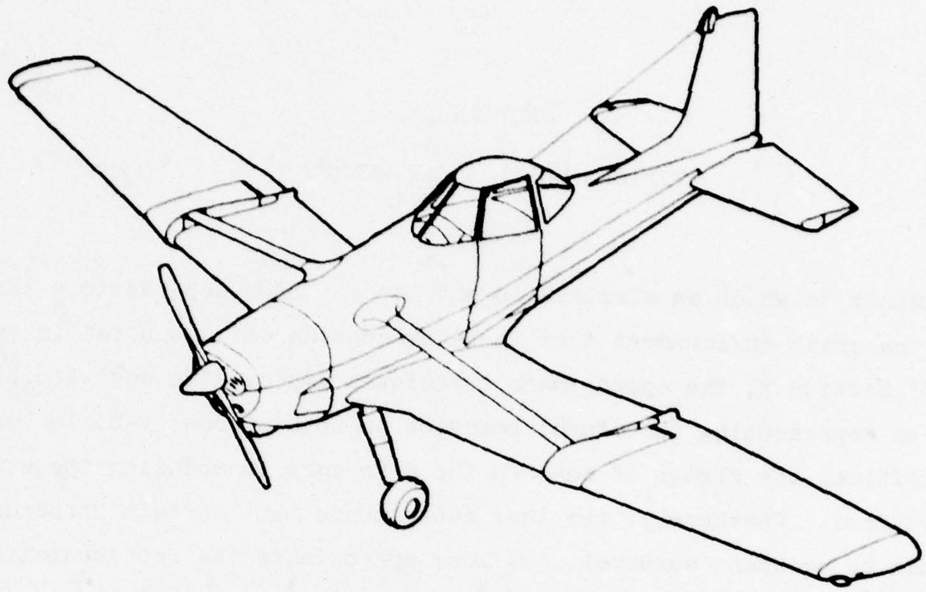


Figure 5-1. Single-Engine, Low-Wing Agricultural Type Airplane

typically weighs between 2500 and 4000 pounds, although with certain restrictions, this type can exceed 4000 pounds maximum takeoff weight. There currently is one airplane of this type that has a maximum takeoff weight as high as 6000 pounds. The forward and mid fuselage is typically of welded steel tube construction. The wings are of 1, 2 or 3 spar arrangement with supporting brace struts. The tail unit is generally an all-metal cantilever design. A representative math model is shown in Figure 5-2, and consists of 50 masses and 95 elements. Seat and occupant representations in the structural model will add at least 2 masses and 5 members (4 for the seat one for the occupant) to this total. If a DRI is included, one more member and mass is required. This is a rather large model for KRASH and represents a desirable upper limit for this type of airplane and structure.

For most accidents involving this type of airplane for which modeling will be performed, the user should be able to reduce the structure mass and

member requirements to 44 masses and 85 members without any significant compromise in the results. Mass numbers 44 through 50 and members 1-44, 1-45, 1-46, 28-49, 29-50, 30-47, 31-48, 16-47, 47-48, 5-47 and 49-50 can be eliminated and the masses redistributed appropriately to achieve such a reduction. For selected conditions a symmetrical (about the centerline) model of the airplane can be utilized which would reduce size requirements from 40 to 50 percent.

The model shown in Figure 5-2 would not be appropriate for modeling occupant behavior. At best the model would provide floor structural responses to be used as inputs to occupant-restraint system math models. KRASH has not been used to model occupant-restraint systems; consequently, it is recommended at this time that it not be used for this purpose.

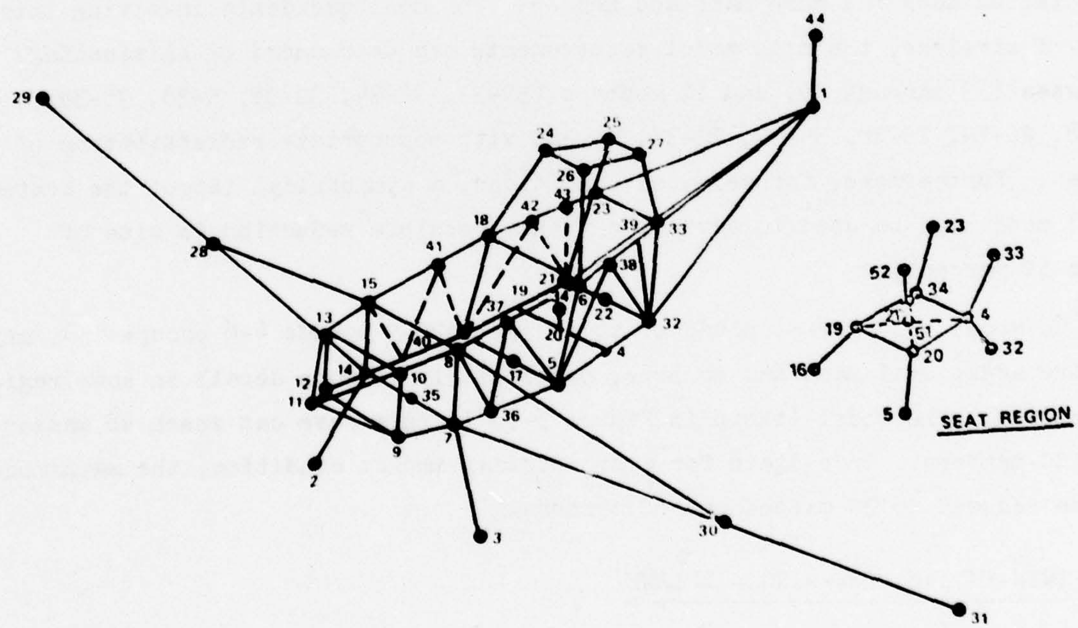


Figure 5-2. Typical Math Model Representation for Single-Engine, Low-Wing Agricultural Type Airplane

5.2 SINGLE-ENGINE, HIGH-WING AIRPLANE

Figure 5-3 shows an overview of a single-engine, high-wing airplane which can be used for several purposes including training, sport, business, commuting, and pleasure. The forward, mid, and aft fuselage is generally of semi-monocoque construction; the wings have supporting brace struts. The tail is a cantilever design. This type of airplane weighs up to 4000 pounds depending on the mission requirements and the number of occupants it is designed to carry. The math model representation for the smaller lighter weight versions (<2000 pounds) of this type airplane accommodating two people is shown in Figure 5-4. This model consists of 41 masses and 71 members. The representation of two side by side occupants requires an additional 3 masses and 5 members, but it is not recommended without extreme care in the manner in which stiffness and damping properties are selected. The type of structure employed and the vehicle dimensions may result in instabilities unless caution is exercised. A DRI representation adds one more mass and member. For most accidents involving this type of airplane, the math model requirements can be reduced by eliminating 7 masses (33 through 39) and 11 members (32-33, 32-34, 32-35, 5-38, 38-39, 25-38, 26-39, 20-36, 36-37, 23-37, 24-36) with appropriate redistribution of masses. Furthermore, for selected conditions, a symmetrical (about the centerline) model can be used to advantage with a possible reduction in size of 40 to 50 percent.

To model a larger airplane of this type (>2000 pounds 4-6 occupants), may require additional mass and members, particularly if more detail in some regions is desired. The model (shown in Figure 5-5) in this case can reach 48 masses and 100 members. Once again for a symmetrical impact condition, the math model can be reduced to 30 masses and 60 members.

5.3 TWIN-ENGINE, LOW-WING AIRPLANE

Typically, the twin-engine, low wing class of airplanes are larger and heavier than the single-engine class of airplanes. Review of data presented in Reference 9 reveals that the twin-engine class of airplane weighs in excess of 4000 pounds and accommodates from 4 to 11 occupants. A typical example of an airplane ($\approx$ 6000 lb take-off weight) of this class is shown in Figure 5-6.

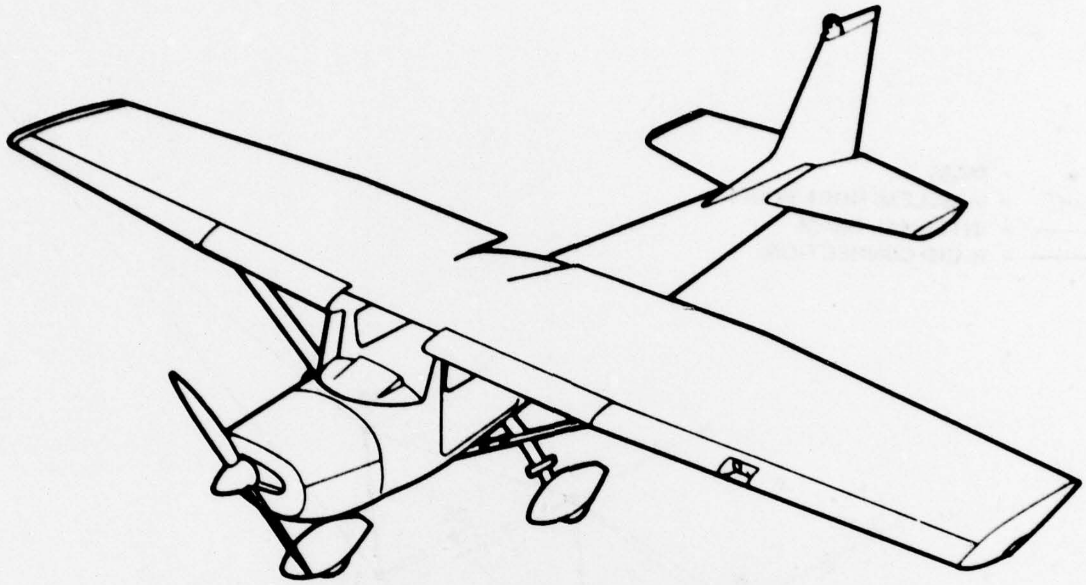


Figure 5-3. Single-Engine, High-Wing Airplane

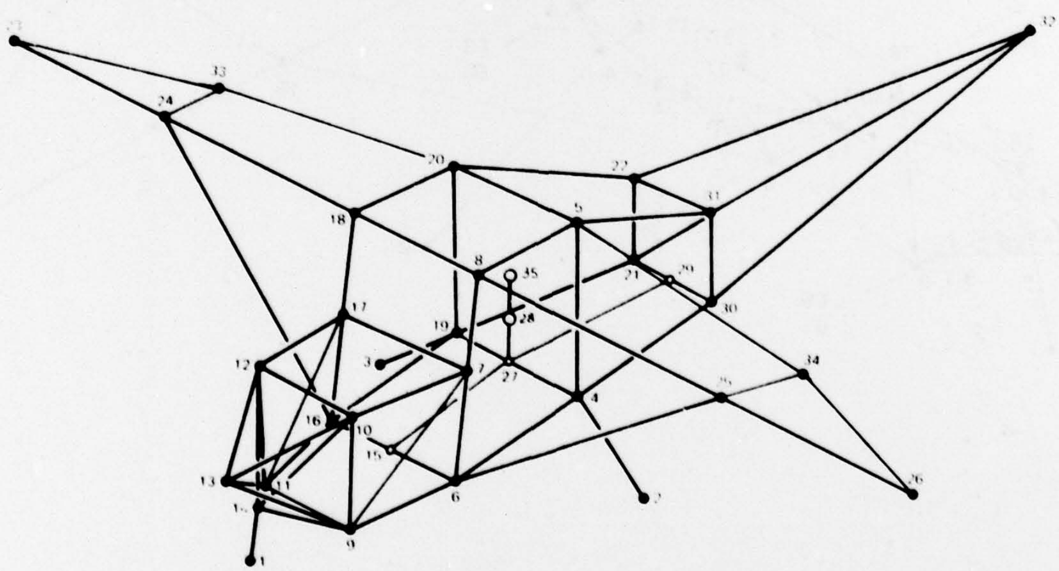


Figure 5-4. Typical Math Model Representation for Single-Engine, High-Wing Airplane (<2000 lb)

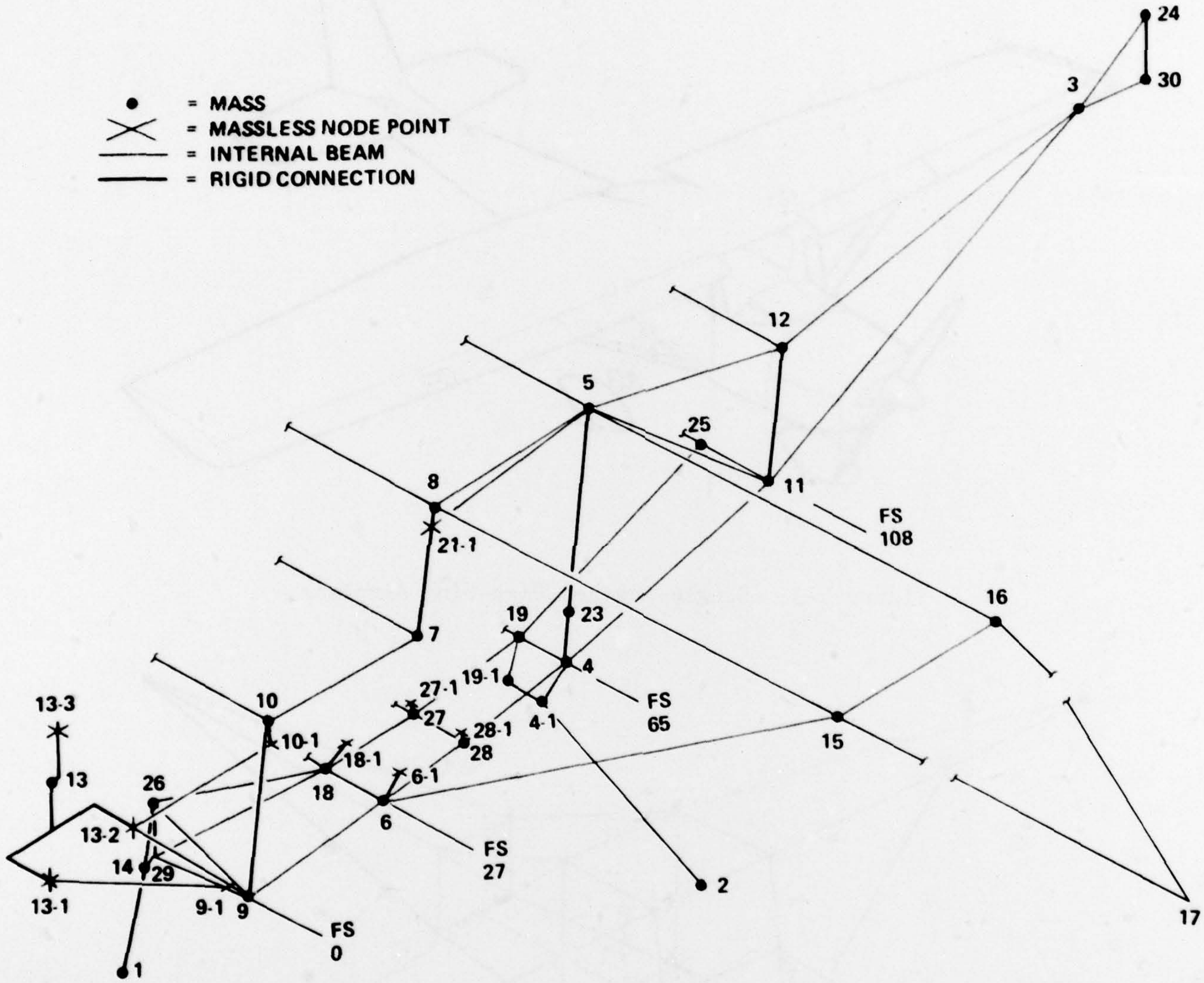


Figure 5-5. Typical Math Model Representation for Single-Engine, High-Wing Airplane (>2000 lb)

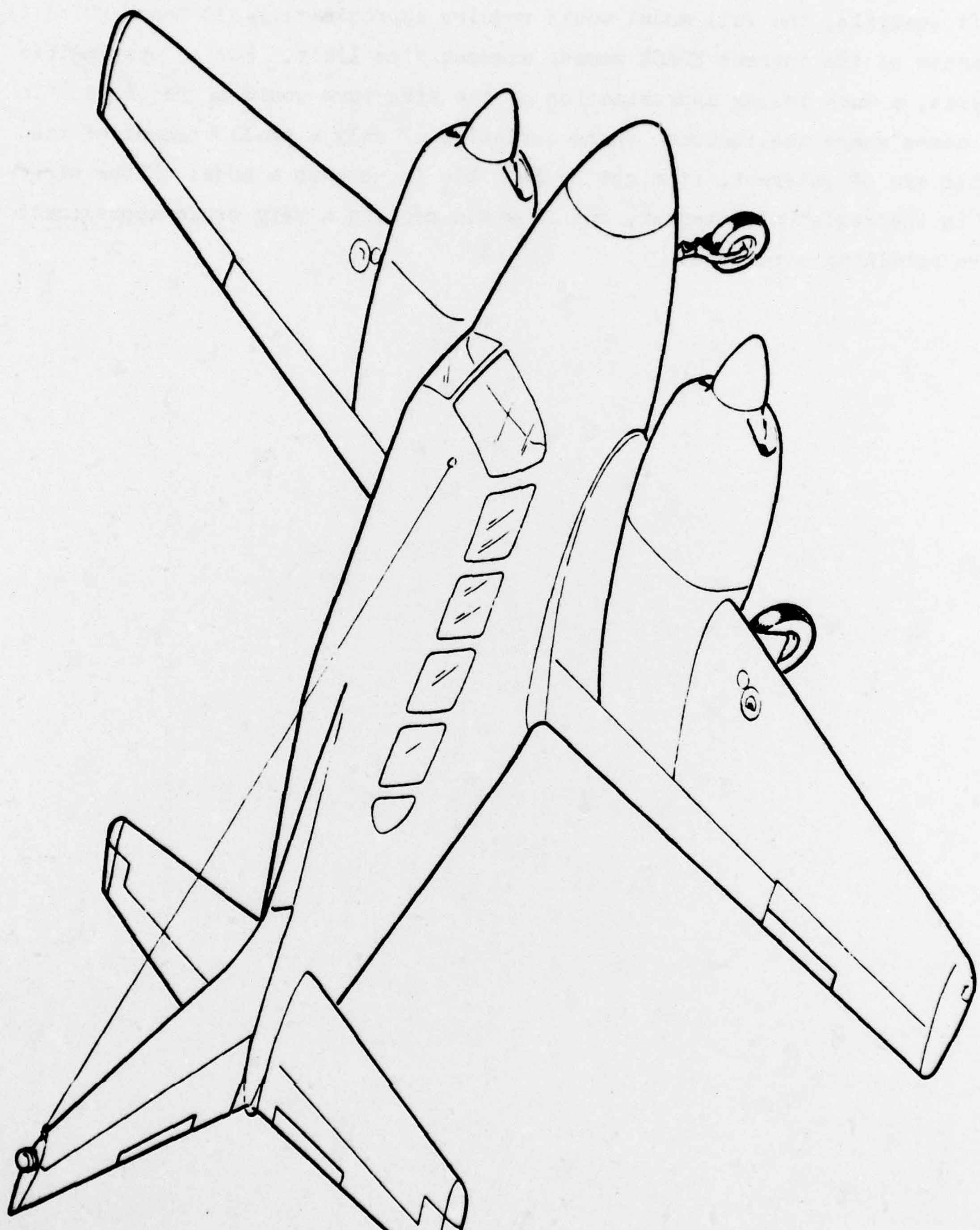


Figure 5-6. Typical Twin-Engine, Low-Wing Airplane

A typical symmetrical model arrangement is shown in Figure 5-7. The model consists of 39 mass elements, and 85 linear beam elements. For a symmetric analysis, the full model would require approximately 130 beams which is in excess of the current KRASH member element size limit. For an unsymmetric analysis, a much cruder approximation of the structure would be required. In some cases where the response characteristics of only a small segment of the vehicle are of interest, it might be possible to develop a model of the structure in the region of interest, but it would require a very crude approximation of the remaining structure.

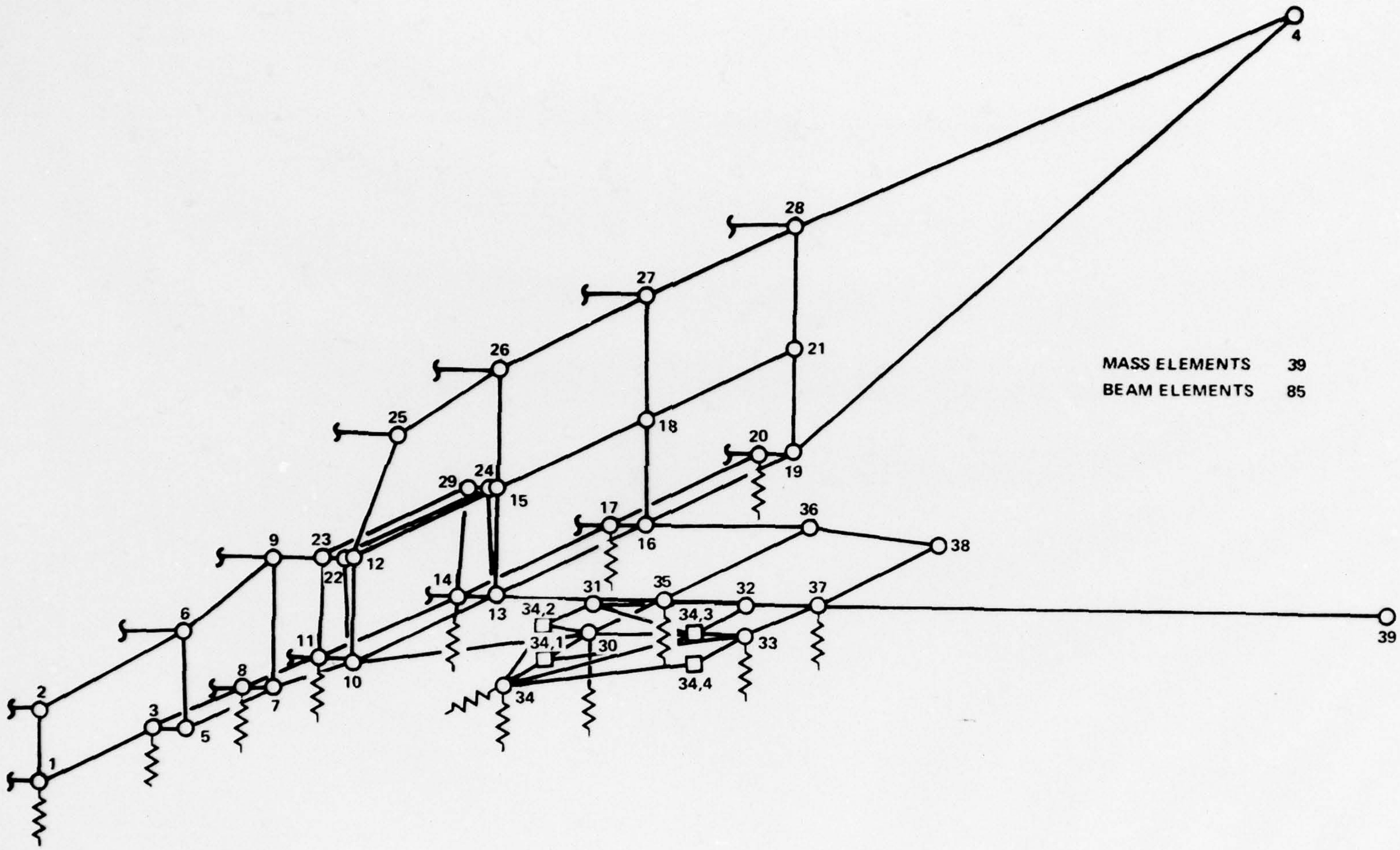


Figure 5-7. Symmetric Twin-Engine, Low-Wing Airplane Model

SECTION 6

REFERENCES

1. Gamon, M. A. GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS - USER'S MANUAL, VOLUME I, PROGRAM KRASH THEORY, Lockheed-California Company, FAA-RD-77-189 I, Federal Aviation Administration, Wash. D.C., Feb. 1978.

2. McNeese, D.C., and Hoag, A.L., ENGINEERING AND TECHNICAL HANDBOOK, Prentice-Hall, 1957.

3. Gamon M.A., Wittlin, G., EXPERIMENTAL PROGRAM FOR THE DEVELOPMENT OF IMPROVED HELICOPTER STRUCTURAL CRASHWORTHINESS ANALYTICAL AND DESIGN TECHNIQUES, Lockheed-California Company; USAAMRDL Technical Report 72-72A, 72B, U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., 1973.

4. Park, K.C., Wittlin, G., DEVELOPMENT AND EXPERIMENTAL VERIFICATION OF PROCEDURES TO DETERMINE NONLINEAR LOAD-DEFLECTION CHARACTERISTICS OF HELICOPTER SUBSTRUCTURES SUBJECTED TO CRASH FORCES, USAAMRDL-TR-74-12A, 12B, U.S. Army Air Mobility Research and Development Laboratory, Ft. Eustis, Va., 1974.

5. Roark, R., FORMULAS FOR STRESS AND STRAIN, McGraw Hill, 1965.

6. Gamon, M.A., THE DEVELOPMENT OF DYNAMIC TAXI DESIGN PROCEDURES, FAA Technical Report DS-68-11, 1968.

7. Gerard, G., HANDBOOK OF STRUCTURAL STABILITY, NACA TN 3781-3785, 1957.

8. Turnbow, J.W., et al, CRASH SURVIVAL DESIGN GUIDE, DYNAMIC SCIENCES, USAAMRDL TR 71-22, Eustis Directorate, U.S. Army Air Mobility and Research Laboratory, Ft. Eustis, Va., Oct. 1971.

9. Wittlin, G., Gamon, M.A., A METHOD OF ANALYSIS FOR GENERAL AVIATION STRUCTURAL CRASHWORTHINESS, Lockheed-California Company, FAA-RD-76-123, Federal Aviation Administration, System Research and Development Service, Washington, D.C., Sept. 1976.

10. Wittlin, G., Gamon, M.A., LaBarge W.L., FULL-SCALE CRASH TEST EXPERIMENTAL VERIFICATION OF A METHOD OF ANALYSIS FOR GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS, Lockheed-California Co., FAA-RD-77-188, Federal Aviation Administration, Washington, D.C., Feb. 1978.

11. Laananeen, D.H. Dr., DEVELOPMENT OF A SCIENTIFIC BASIS FOR ANALYSIS OF AIRCRAFT SEATING SYSTEMS, FAA-RD-74-130, Federal Aviation Administration, Jan. 1975.

12. Wittlin, G., GENERAL AVIATION AIRPLANE STRUCTURAL CRASHWORTHINESS-USER'S MANUAL, Volume III - RELATED DESIGN INFORMATION, Lockheed-California Company, FAA-RD-77-189III, Federal Aviation Administration, Washington, D.C., Feb. 1978.

13. Crenshaw, B.M., et al, AIRCRAFT LANDING GEAR DYNAMIC LOADS FROM OPERATIONS ON CLAY AND SANDY SOIL, AFFDL-TR-69-51, Air Force Flight Dynamics Laboratory, Dayton, Ohio, Feb. 1971.

14. Massonnet, C.E., Save, M.A., PLASTIC ANALYSIS AND DESIGN Vol. I, Beams and Frame, Chapter 2, Blarsdell Publishing Co., Plastic Beading, 1965.

APPENDIX A

SHOCK STRUT ELEMENT DESCRIPTION

A.1 GENERAL

The use of a shock strut element in KRASH is available for, but not limited to, landing gear oleo struts. The following discussion will be oriented to landing gear oleo strut usage. The axial strut motion is assumed to be uncoupled from the transverse displacements. Axial forces are produced by an air spring force, F_{A_i}, a hydrualic damping force, F_{O_i}, a friction force, F_{F_i}, and forces produced by elastic stops which limit the travel of the piston within the cylinder at full extension and full compression. Each of these forces is discussed separately.

A.2 AIR SPRING FORCE

The expression for the air spring force is

$$F_{A_i} = F_{A_{O_i}} \left(\frac{E_i}{E_i - y_i} \right)^{n_i} - F_{A_{A_i}} \qquad (A.1)$$

where

E_i = effective total strut cylinder length (Figure A-1)

$F_{A_{O_i}}$ = strut air preload at $y_i = 0$

$F_{A_{A_i}}$ = cylinder load due to ambient air

n_i = polytropic exponent

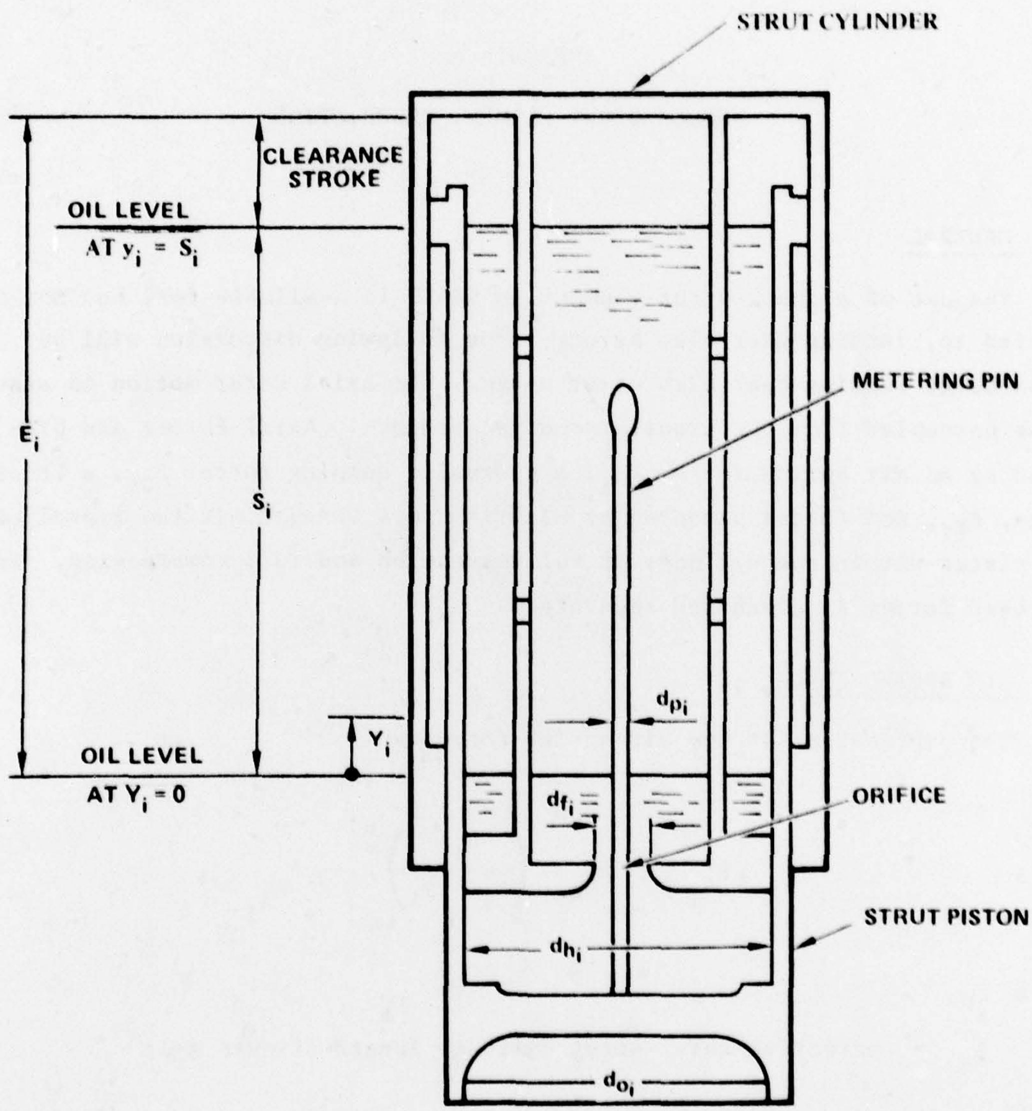


Figure A-1. Schematic of Oleo Strut

y_i = shock strut closure displacement, varying with time

$F_{A_{o_i}}$ is given by

$$F_{A_{o_i}} = \pi/4 \left(p_{oi} \, d_{oi}^{\,2} \right) \tag{A.2}$$

where p_{oi} is the absolute air pressure in the upper chamber of the shock strut at full extension (y_i = 0) and d_{oi} is the effective pneumatic diameter as shown in Figure A.1.

If $F_{A_{S_i}}$ is the strut bottoming load at $y_i = s_i$, the value of E_i can be obtained from equation (A.1) as

$$E_i = \frac{S_i}{1 - \left(\dfrac{F_{A_{o_i}}}{F_{A_{S_i}} + F_{A_{A_i}}} \right)^{1/n_i}} \tag{A.3}$$

where S_i is the stroke. For high velocity impact conditions, a polytropic exponent of 1.4, representing adiabatic conditions, is appropriate.

In the program the values of E_i, $F_{A_{o_i}}$, $F_{A_{A_i}}$, S_i and n_i are input as EOLEO, FAO, FAA, YMAX and EXPOLE, respectively.

A.3 HYDRAULIC DAMPING

The hydraulic damping force F_{o_i} is given by

$$F_{o_i} = C_{z_i} \left| \dot{y}_i \right| \dot{y}_i \tag{A.4}$$

where

$\dot{y}_i$ = shock strut closure velocity, varying with time

$|y_i|$ is the absolute value of $\dot{y}_i$ and C_{z_i} is a damping constant which is a function of the strut orifice characteristics B_i and of the characteristics B_{r_i} of a strut rebound valve. C_{z_i} is defined as

$$C_{z_i} = B_i \quad \text{if} \quad \dot{y}_i \geq 0$$
$$C_{z_i} = B_{r_i} \quad \text{if} \quad \dot{y}_i < 0 \qquad (A.5)$$

B_i is defined by

$$B_i = \frac{Y A_{h_i}^3}{2g\,(A_{f_i} C_d)^2} \qquad (A.6)$$

where

$A_{f_i} = \pi/4\,(d_{f_i}^{\,2} - d_{p_i}^{\,2})$ = net orifice area

C_d = orifice discharge coefficient (typical value = 0.85)

Y/g = oil density (typical value = 0.992 E-4 $\frac{\text{lb-sec}^2}{\text{in}^4}$)

$A_{h_i} = \pi/4\left(d_{h_i}^{\,2}\right)$ = effective hydraulic area

d_{f_i}, d_{p_i} and d_{h_i} are the orifice, metering pin and effective hydraulic diameters, respective (see Figure A.1).

B_i and B_{r_i} are input into the program, as BOLEO and BROLEO Both terms should be functions of y_i to simulate the effects of a metering pin and variable rebound snubbing. However, currently they are input as constant values.

A.4 FRICTION FORCE

Coulomb friction is modeled, so that the magnitude of the friction force is independent of velocity, while the direction of the force is opposite to the direction of the strut velocity.

The friction forces, F_{F_i}, are given by

$$F_{F_i} = C_i f(\dot{y}_i) \tag{A.7}$$

where $f(y_i)$ is a function whose sign is always equal to that of $\dot{y}_i$ and whose magnitude is 1.

Stictly speaking, $f(\dot{y}_i)$ should be equal to 1.0 for all positive values of $\dot{y}_i$ and equal to -1.0 for all negative values of $\dot{y}_i$. However, since the friction force is a passive force and is only present as a reaction to an applied force, the friction force will be able to attain its full value only if the applied force is greater than C_i. If this situation is not the case, stops will occur in the motion. A rigorous treatment of this problem would introduce unwarranted complications into the program. A very good approximate solution which avoids the difficulty can be obtained by letting the friction force vary sufficiently slowly from C_i to $-C_i$ at small values of $\dot{y}_i$, so that at each step in the integration process equilibrium of the forces is obtained without introducing large discontinuities. The following form is therefore assumed for $f(\dot{y}_i)$:

$$f(\dot{y}_i) = \tanh(\dot{y}_i/\alpha_o) \tag{A.8}$$

This function is plotted in Figure A-2 for various values of α_o. The value of α_o should be small enough to simulate the friction force with sufficient accuracy, but not so small as to introduce discontinuities. The minimum value will depend on the integration interval. Generally a value of $\alpha_o = 1$ is found to be suitable. The expression for the friction force becomes

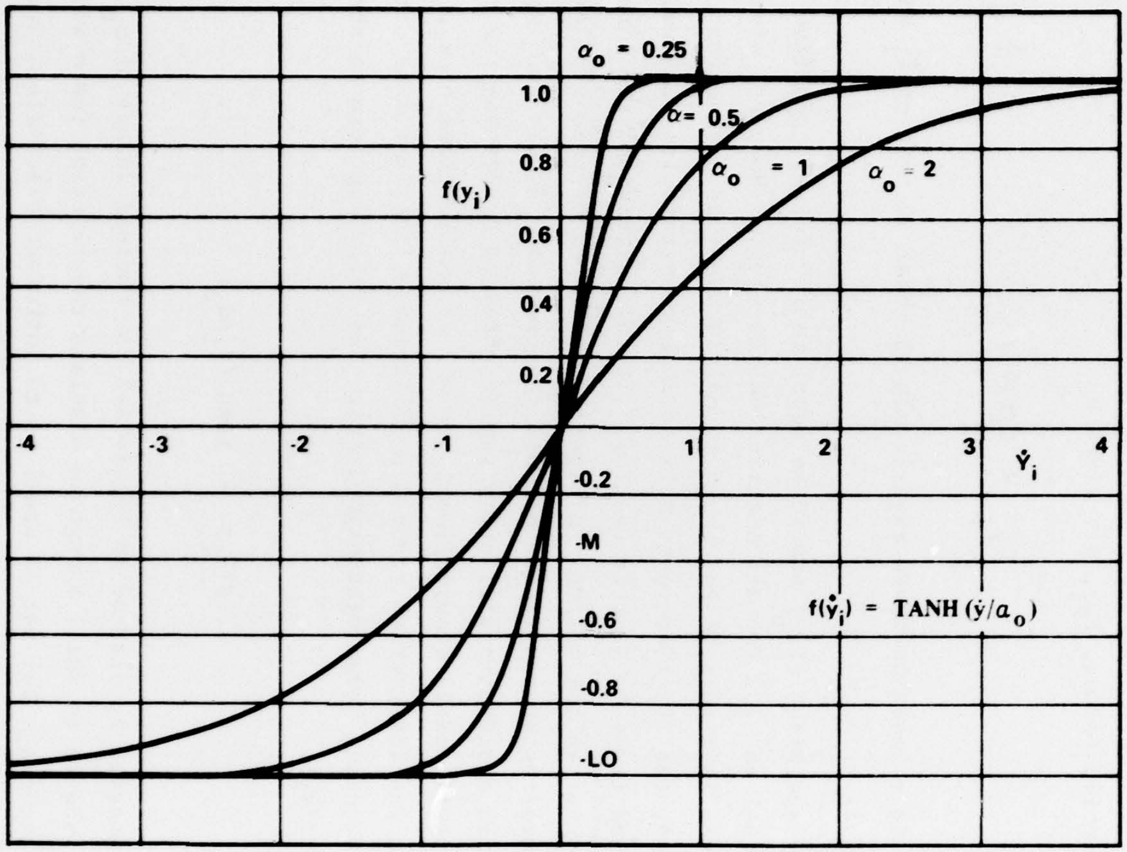


Figure A-2. Friction Force Coefficient as Function of Strut Closure Velocity

$$F_{F_i} = C_i \tanh (\dot{y}_i/\alpha_o) \qquad (A.9)$$

The values of α_o and C_i are input as ALPHAP and FCOUL in the program.

A.5 ELASTIC STOPS

Two elastic stops of stiffness K_{E_i} and K_{c_i} are present which limit the travel of the piston at full extension and full compression, respectively. The forces generated by these stops are, therefore, equal to $K_{E_i}\ Y_i$ when $y_i < 0$ and $K_{c_i}\ (y_i - S_i)$ when $y_i > S_i$.

Collecting all the above terms the total axial force F_i can be written as

$$F_i = F_{A_i} + F_{o_i} + F_{F_i} + F_{EXT_i} + F_{COMP_i} \qquad (A.10)$$

The terms K_{E_i}, K_{c_i}, and S_i are input into the program as XKEXT, XKCOMP, and YMAX, respectively.